Final Report

Measurement Allowance Project – On-Road Validation

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Abstract

Regulations were promulgated requiring the measurement of emissions from diesel engines while operating within the Not-To-Exceed (NTE) control area of the engine map. These measurements require the use of portable emissions measurement systems (PEMS) rather than traditional laboratory methods. To provide input into the determination of a measurement "allowance" that would account for differences between a laboratory measurement and PEMS, a comprehensive Measurement Allowance testing project was set-up and governed by the Measurement Allowance Steering Committee (MASC). In the first phase of the project emissions measured with PEMS and federal reference were compared for an engine on a dynamometer while the environmental conditions were changed for the PEMS unit. These data were fitted to a Monte Carlo model. In a second phase, the goal was to compare the measurements from PEMS with federal reference methods during actual in-use driving using the University of California, Riverside (UCR) Bourns College of Engineering – Center for Environmental Research and Technology's (CE-CERT) Mobile Emissions Laboratory (MEL). Prior to the on-road testing portion, MEL underwent an audit following 40CFR Part 1065 and a side-by-side comparison with emissions measured at the SwRI laboratory. Results were viewed to be comparable. This report focuses on the on-road comparison of the PEMS measuring in the raw exhaust with gaseous instruments measuring flow and concentrations from a full dilution tunnel according to the Code of Federal Regulations (CFR). For comparison, simultaneous emissions measurements using MEL and PEMS were carried out over three routes designed to capture different driving and environmental conditions, such as temperature and elevation. The results of this program were used to validate the Monte Carlo model by comparing over-the-road results against the Monte Carlo model predictions and evaluating if the model correctly predicted the PEMS error relative to the CFR-compliant MEL.

Executive Summary

In recent years, the US Environmental Protection Agency (EPA) and the California Air Resources Board (CARB) have promulgated regulations to further control diesel emissions. Recent regulations have targeted in-use emissions and the protocols required to make those measurements. These regulations require that in-use measurements to be made with portable emissions monitoring systems (PEMS) and that emissions be evaluated under conditions within the NTE zone or over NTE events. An NTE event is defined based on different operating conditions in the NTE zone (e.g., torque and power $\geq$ 30% of the maximum value) that must be met for a period of at least 30 seconds.

With the importance of PEMS in meeting regulatory requirements, more information was needed about the variation of measurement during in-use operation. In response to this need, a Measurement Allowance Steering Committee (MASC) and comprehensive Measurement Allowance testing program were established to determine the “allowance” for compliance purposes when PEMS are used for in-use testing. Members of the MASC include EPA, ARB, and the Engine Manufacturers Association (EMA). This Measurement Allowance program included a series of laboratory tests on an engine dynamometer and in environmental chambers at the Southwest Research Institute (SwRI) and Monte Carlo modeling. An important element of the Measurement Allowance program required the measurement of in-use emissions by the federal reference instruments in UCR’s Mobile Emissions Laboratory (MEL) in comparison with those of a PEMS unit. Before carrying out the in-use emissions measurements, MEL underwent a 40CFR Part 1065 audit and side-by-side comparison of emissions measurements with an engine operated on a dynamometer at SwRI. After establishing the emissions measured by UCR and SwRI were equivalent, the in-use validation measurements were made on a class 8 truck over various routes designed to emphasize operation in the NTE zone.

1065 Audit

The first step in the project required that UCR’s MEL undergo a 40CFR Part 1065 self-audit using the protocol developed by SwRI and agreed to by the US EPA. The 1065 self audit of MEL included water (H_2O) and carbon dioxide (CO_2) interference/quench checks, nitrogen dioxide (NO_2) to nitrogen oxide (NO) converter efficiency checks, non-methane hydrocarbons (NMHC) cutter penetrations fractions. In addition the linearity of all analyzers, mass flow controllers, and temperature and pressure sensors was verified. All checks were found to pass and the system to comply with 40CFR Part 1065.

Cross Correlation with Southwest Research Institute Engine Laboratory

In the next step, a cross correlation of measured emissions concentrations and flow rates was conducted between an engine dynamometer test cell at SwRI and UCR’s MEL. For this task, the MEL was towed to SwRI in San Antonio and set-up such that UCR’s MEL could make measurements from the same engine dynamometer test cell being used by SwRI. This represented a unique opportunity to evaluate the comparison between two 1065 compliant laboratories under the same conditions including the test engine and dynamometer, test location, and test cycles. This setup was selected to demonstrate that in-lab and on-road measurement platforms would give equivalent results.

The correlation was performed for two cycles: one cycle based on a series of NTE events and another based on the Ramped Modal Cycle (RMC). Testing was performed on a 2005, 14 liter Detroit Diesel Corporation (DDC) Series 60 engine. For the NTE emissions cycle, the MEL was 2.1% higher than the SwRI measurement for oxides of nitrogen (NO_x) and 2.7% higher than SwRI for CO_2. For the RMC, the MEL was 3.8% higher than the SwRI measurement for NO_x and 2.3% higher than SwRI for CO_2. THC and CO emissions were at relatively low levels and showed larger deviations (-65 to -92% for THC and -16 and -24% for CO). The members of the MASC concluded the results were acceptable to allow continuation of the on-road portion of the measurement allowance program.

On-Road Comparisons between the MEL and the PEMS

On-road comparisons of the MEL and the PEMS measurements were made over three different driving routes. The routes included round trips to a San Diego and Bishop, CA. The tests were conducted using a truck that was equipped with a 475 hp Caterpillar C-15 ACERT engine and a diesel particulate filter to provide emission levels comparable to those anticipated for 2007 for PM, THC, and CO. A total of 6 test runs and 3 audits runs were conducted during the on-road testing phase, including:

1. Three Audit runs without the PEMS
2. Three runs with PEMS positioned inside the cab
3. Three runs with PEMS positioned outside the cab.

During the audit runs, the measured values were compared to the audit bottle concentrations over the course of the test route. For NO_x and CO_2, the measurements were both within 2% of the audit bottle concentration over the course of the three different test runs. THC and CO audits were within ~ 1 ppmv or 5% of the audit bottle concentrations, even though these bottles were at the low levels expected for a DPF equipped vehicle. Ambient background levels for NO_x and CO_2 were relatively low compared to the diluted exhaust levels. THC and CO background concentrations were comparable to those found in the diluted exhaust of the DPF equipped vehicle.

Over the course of the six test runs, a total of 426 NTE events were identified. Of these 426 events, 26 events were identified by only the MEL or PEMS, but not by both. For an additional 57 events, the start of the NTE events between the MEL and PEMS differed by more than 2 seconds or the duration of the NTE event differed by more than 1 second. NTE events where the data did not pass the drift limit validity check were also excluded. This included all the data from the first test day since the post-test zero span data were not available. The on-road test results presented below are based on this subset of data.

It is important to note the routes for the on-road validation were structured to emphasize data collection within the NTE zone of engine operation. That is, while the overall driving routes included some stop-and-go vehicle/engine operation, data were generally recorded only during higher speed, quasi-steady-state engine operation. Very little data collection occurred during vehicle/engine operation under stop-and-go driving conditions, which generate few NTE events.

The brake specific emission comparisons for NO_x, THC, and CO were calculated using three different methods:

1. based on engine speed and torque
2. based on brake specific fuel consumption
3. based on mass fuel flow or a fuel specific method.

The brake specific NO_x emissions for matching NTE events are provided in Figure ES-1 and values for the PEMS measurements were consistently higher than those for the MEL, with a correlation of R^2~0.84/0.85 between the measurement methods. The deviations relative to the NTE NO_x standard of 2.0 grams per brake horsepower-hour or 2.68 grams per brake kW-hour are presented in Figure ES-2. The absolute deviations as a function of the total NO_x emissions as measured by the MEL are provided in Figure ES-3. The deviations were greatest for Method 1 with an average deviation of +8%±4% relative to the standard, where the error represents one standard deviation. The deviations for Methods 2 and 3 were +4%±5% and +3%±5%, respectively, at one standard deviation. The differences in deviations for the three calculation methods could be related to the incorporation of CO_2 exhaust measurements into calculation methods 2 and 3, which are also biased high for the PEMS, or to the impacts of differences in analyzer dispersion on the calculations. Some differences appeared between the different test runs/days, although overall these trends were weak for different environmental conditions (in cab vs. out of cab) or between the different routes (i.e., San Diego, Riverside to Bishop, and Bishop to Riverside).

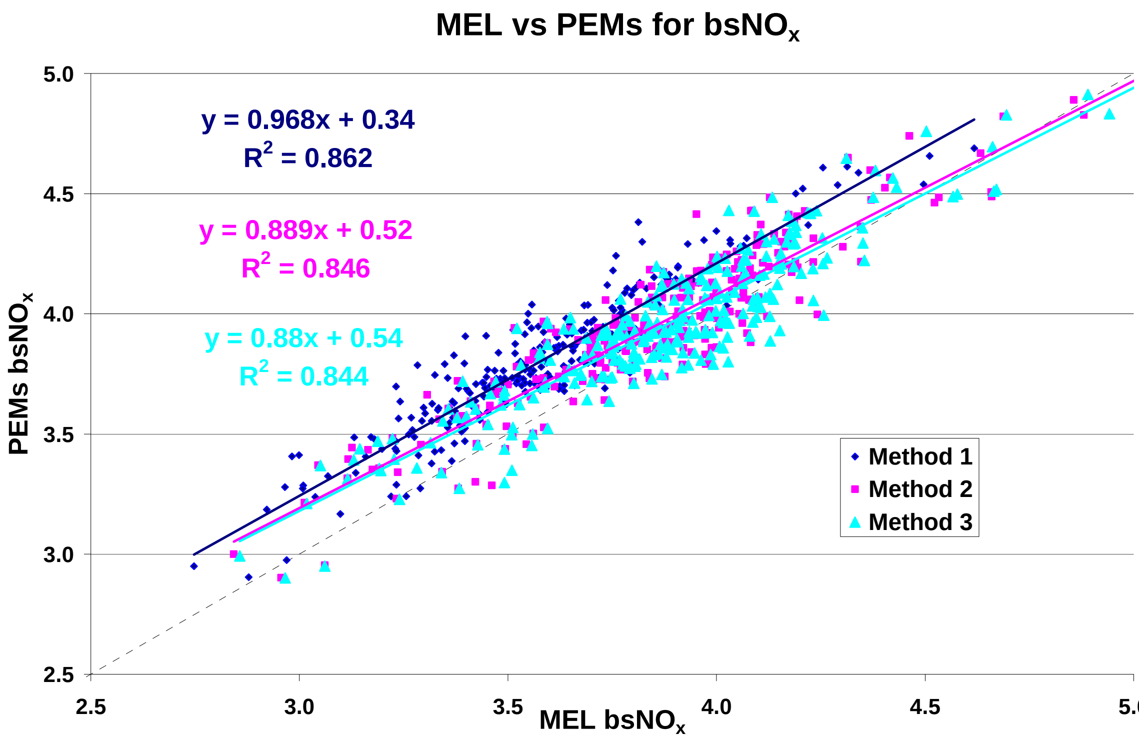

Figure ES-1. NO$_x$ Mass Emissions (g/bkW-hr) for PEMS Relative to MEL

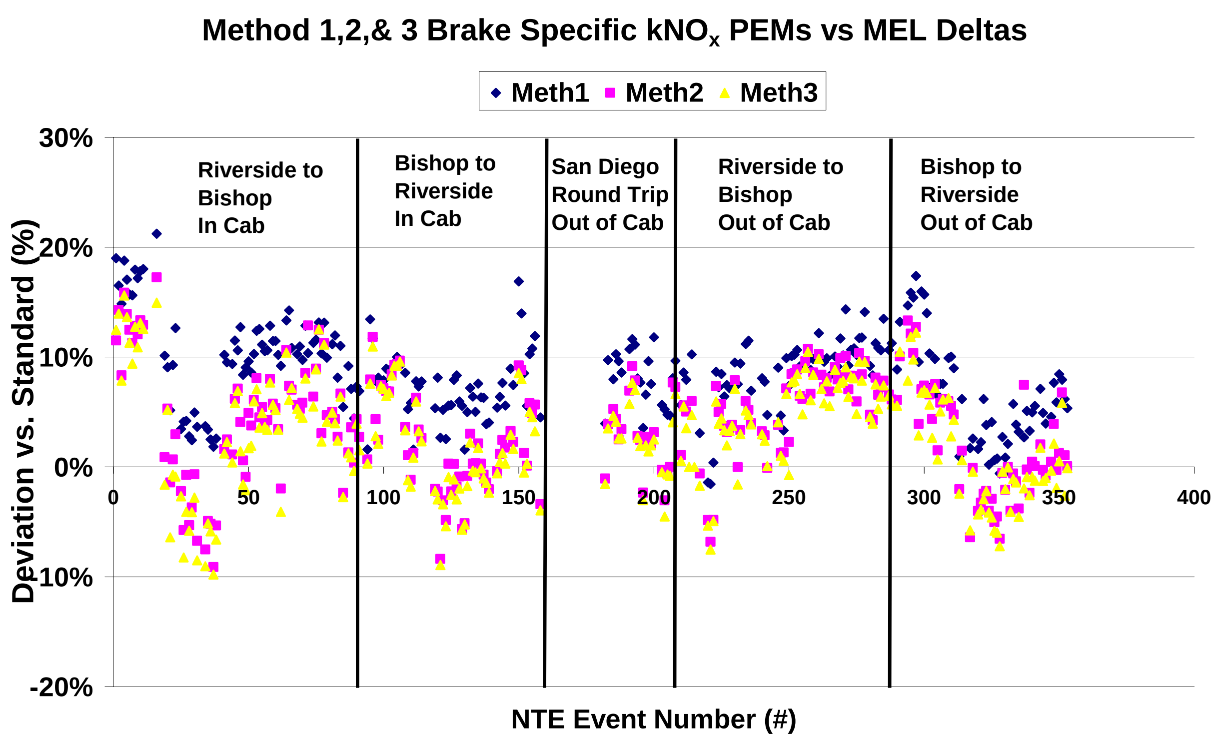

Figure ES-2. Relative Deviations vs. NTE Standard for NO$_x$ on an NTE Event Basis

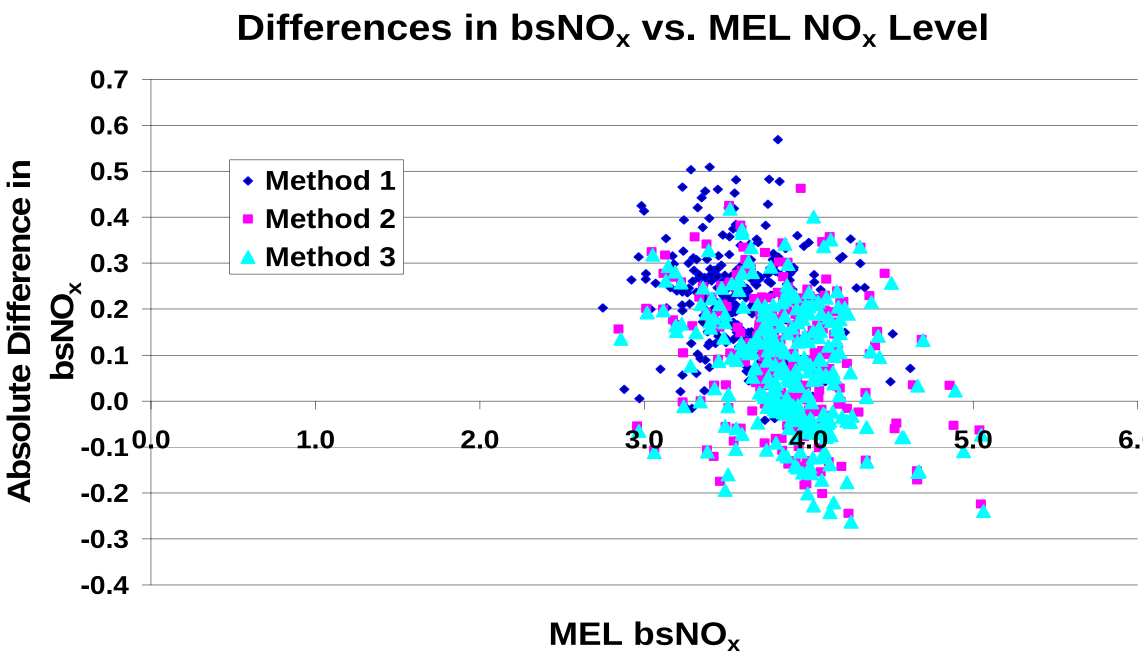

Figure ES-3. Absolute Differences for NO_x (g/bkW-hr) Compared to NO_x Emission Level (g/bkW-hr)

The correlation for brake specific CO_2 emissions for matching NTE events is provided in Figure ES-4. The method 1 brake specific CO_2 emissions for the PEMS were consistently biased high relative to the MEL, with an average deviation of +4%±2%. There was a good correlation between the MEL and PEMS method 1 CO_2 measurements ($R^2 = 0.97$). Note for the methods 2 and 3, the resulting brake specific CO_2 emissions primarily represent the values derived from the mass fuel flow from the ECM for both the MEL and PEMS since the measured CO_2 concentrations cancel out of the equation.

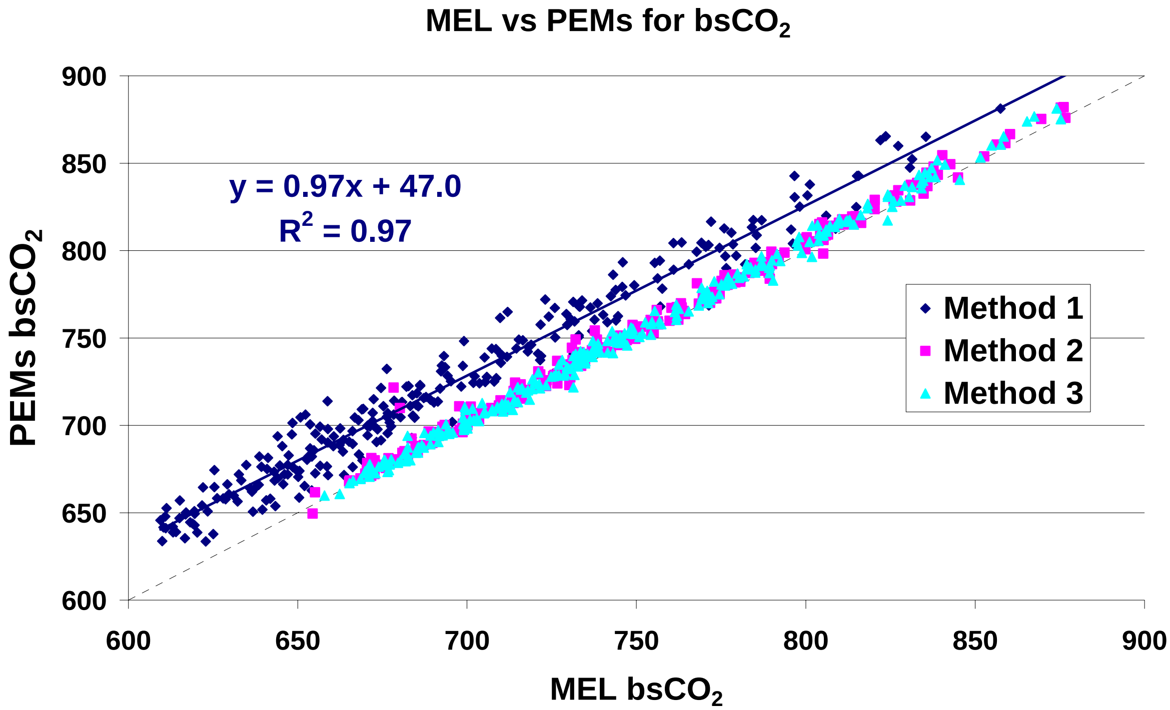

Figure ES-4. CO_2 Mass Emissions (g/bkW-hr) for PEMS Relative to MEL

As a consequence of the installed diesel particulate filter, the NMHC and CO emissions levels were consistently low. For the MEL, the diluted exhaust concentrations were comparable to those of the ambient background. The average emission rates for NMHC were 0.003 g/bkW-hr or below, which is approximately 1% of the anticipated NTE standard of 0.28 g/bkW-hr. There is not consistent bias for NMHC emissions between the different analyzers, with the PEMS higher for some tests and lower for others, albeit at very low levels. Average differences for the different test runs were ±0.5% or less of the NTE standard. There was a weak correlation (R^2 ~0.36/0.37) between the MEL and PEMS measurements due to the low level measurements.

CO emissions levels were also consistently low during the on-road measurements. For the MEL, the diluted exhaust concentrations were comparable to those of the ambient background. The PEMS measurements were consistently higher than those of the MEL. The CO emissions levels were on the order of 0.1% of the anticipated NTE standard of 26.01 g/bkW-hr for CO for the MEL measurements. The absolute differences represented approximately 1% of the NTE standard, although the PEMS measurements were approximately an order of magnitude higher than those for the MEL. The correlation analysis showed that there was essentially no correlation between the measurement methods (R^2 = 0.0011 or less) at these low levels.

Final Measurement Allowance Values

The results of this study were used in the development of the measurement allowances for gaseous emissions (NO_x, THC, and CO). The measurement allowances were determined using the engine testing, environmental testing, and Monte Carlo modeling performed at SwRI, in conjunction with the validation data obtained from the CE-CERT MEL. Initial model simulation runs showed that the model was validated by the on-road testing data only for the method 1 calculations for NO_x, for all three calculation methods for NMHC, and for none of the calculation methods for CO. The EPA and CARB continued to work with SwRI and conduct additional testing and modeling analysis in an effort to validate all three measurement methods (including method 2 and 3). This subsequent work resulted in the validation of all three methods. After further discussion with the EMA and engine manufacturers, it was agreed that the newly validated and more stringent measurement allowances would be used when conducting the HDIUT program on 2010 and subsequent model year heavy-duty diesel engines (HDDEs), while the initial method 1 validated measurement allowances would still be allowed for 2007 through 2009 model year (HDDEs). The final measurement allowance values by model year are presented in Table ES-1.

Pollutant	2007 – 2009 Model Year	2010 and Subsequent Model Year
NO_x	0.45	0.15
NMHC	0.02	0.01
CO	0.50	0.25

1 Grams per brake-horsepower-hour

Table ES-1. HDIUT Measurement Allowance Values by Model Year (g/bhp-hr)[1]

1.0 Background

Diesel engines are one the most important emissions sources to control for continued improvement in air quality due to their contribution to the emissions inventory for oxides of nitrogen (NO_x) and particulate matter (PM). In recent years, the US Environmental Protection Agency (EPA) and the California Air Resources Board (CARB) have promulgated regulations to further control diesel emissions. The most recent regulation has targeted in-use emissions in a defined portion of the engine map known as the Not-To-Exceed (NTE) control area and the protocols required to make those measurements.

The new requirement to measure in-use emissions means that portable emissions measurement systems (PEMS) will be needed rather than the fixed laboratory measurements. However, as comparative data for Federal Reference Methods and PEMS were scarce, the regulatory agencies and engine manufacturers created the Measurement Allowance Steering Committee (MASC) to develop a comprehensive testing program for determining the measurement allowance. From the MASC evolved the design of a comprehensive program that was published on the EPA web site on June 3, 2005 (http://www.epa.gov/otaq/hd-hwy.htm). The program includes engine testing, environmental testing and Monte Carlo modeling. A key objective of the Measurement Allowance Program is to determine the "allowance" for compliance purposes when PEMS are used for in-use testing.

One of the main components of the Measurement Allowance test program is the comparison of PEMS and a mobile laboratory platform under in-use conditions. The University of California at Riverside (UCR) Bourns College of Engineering – Center for Environmental Research and Technology's (CE-CERT) Mobile Emissions Laboratory (MEL) was incorporated into the Measurement Allowance test plan for this task. The in-use comparisons include simultaneous measurements by the MEL and the PEMS under different in-use driving conditions designed to generate NTE events and provide a range of environmental conditions, such as temperature and altitude. The results of this in-use comparison will be used to, in part, validate the sensitivity analysis and resultant model based on Monte Carlo simulations of a number of key parameters that are expected to contribute to the measurement allowance. Prior to conducting the on-road tests, a cross laboratory correlation was performed between the MEL and an engine test cell at the Southwest Research Institute (SwRI) in San Antonio, Texas. A 1065 audit of the MEL was also conducted.

1.1 Data Analysis with a Focus on the NTE Zone

The focus of this program is an evaluation of the emissions between PEMS and the CE-CERT MEL under conditions within the NTE zone or NTE events. The NTE zones were defined by agreements between the US EPA, CARB and the engine manufacturers with more information provided in the EPA documents. Paraphrasing the reference: An NTE event is generated when all of the following conditions are simultaneously met for at least 30 seconds or longer if an after treatment device is regenerating.

A listing of NTE conditions is provided in Table 1-1 and the NTE region is illustrated graphically in the Figure 1-1.

1. Speed >15%(n_{hi}-n_{lo}) + n_{lo}	7. Outside petitioned exclusion zones
2. Torque ≥ 30% max	8. Outside of any NTE region in which a manufacturer states that less than 5% of in-use time will be spent.
3. Power ≥ 30% max	9. With EGR, intake manifold temperature ≥ 86-100ºF, depending upon intake manifold pressure.
4. Altitude ≤ 5500 feet	10. With EGR engines, the engine coolant temperature ≥ 125-140ºF, depending on intake manifold pressure.
5. Amb temp ≤ 100ºF sea level to 86ºF at 5500 feet	11. Engine after treatment systems' temperature ≥ 250ºC. Only for NO_x and HC aftertreatment.
6. BSFC ≤ 105% min, non-automatic, non-manual transmission; essentially for series hybrids	

Table 1-1. Specifications for Events Classified in the NTE Zone

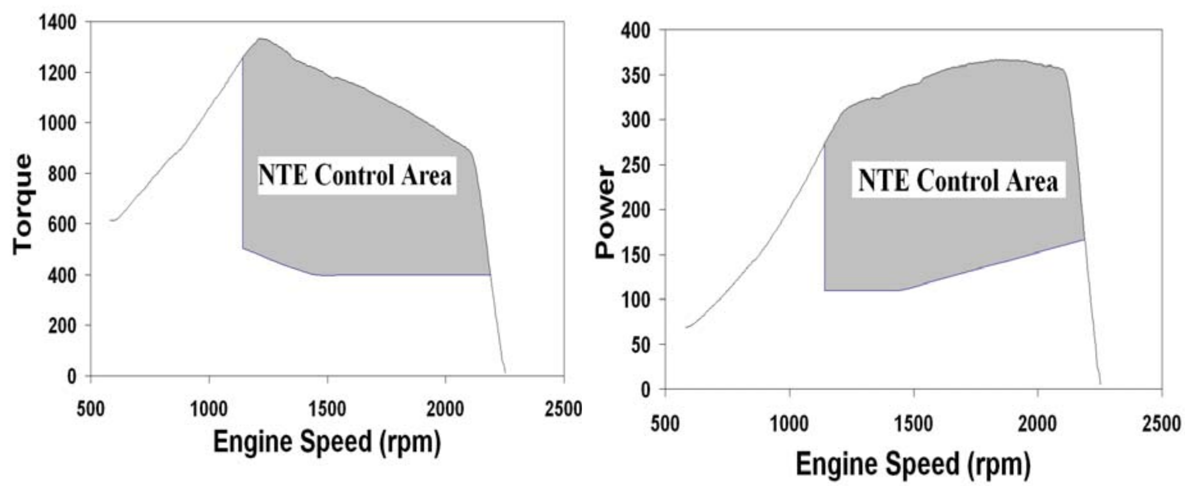

Figure 1-1. Graphical Examples of the NTE Control Area

2.0 1065 Audit CE-CERT Mobile Emissions Laboratory (MEL)

2.1 1065 Audit Overview

As part of the validation of the CE-CERT MEL for the on-road testing, a 1065 self-audit for gaseous emissions was performed on the CE-CERT MEL. A description of the MEL is provided in Appendix A. Prior to conducting the audit, the 1065 regulations were reviewed and the MEL trailer subsystems were modified as needed.

The 1065 self audit of the trailer included water (H_2O) and carbon dioxide (CO_2) interference/quench checks, nitrogen dioxide (NO_2) to nitrogen oxide (NO) converter efficiency checks, nonmethane hydrocarbons (NMHC) cutter penetration fractions. The linearity of all analyzers, mass flow controllers, and temperature and pressure sensors was also verified. The template used for the audit was the same as that used at SwRI and was designed by EPA in conjunction with the Measurement Allowance program.

2.2 1065 Audit Results

A summary of the interference and quenching effects and flame ionization detector (FID) response checks is provided below. All checks were found to pass and the system to be in 1065 compliance.

Verification Description	Measurement		Verification Value	Pass/Fail
1065.350 H_2O interference for CO_2 NDIR [%]	0.001%	±	0.02%	Pass
1065.355 H_2O and CO_2 interference for CO NDIR [ppm]	0.1	±	5.6	Pass
1065.360 FID optimization (methane response)	1.10		N/A	N/A
1065.370 CO_2 and H_2O quench verification for NO_x CLD [%]	-1.71%	±	2.00%	Pass
1065.378 NO_2-to-NO converter conversion [%]	96.4%	±	95%	Pass
1065.365 Nonmethane cutter penetration fractions [%]	1.0%	<	2.0%	Pass

Table 2-1 Summary of 1065 Audit Results

1065.350 H_2O Interference Check for CO_2.

H_2O can interfere with a nondispersive infrared (NDIR) analyzer's response for CO_2. A CO_2 NDIR must have an H_2O interference that is less than 2% of the lowest flow-weighted average CO_2 concentration expected during testing, although an interference of less than 1% is recommended. This test is conducted by bubbling zero gas through a water to create a water saturated test gas that creates a response in the NDIR.

1065.350 H_2O interference for CO_2 NDIR [%]			**Notes**
Dry Zero Air	0.000%		CO2 conc
Wet Zero Air	0.001%		CO2 conc
Interference	**0.001%**		
Dew Point	24.97	degC	DP of wet zero air
Exp. Mean CO_2 Conc.	0.81%		Transient cycle
Criteria	**0.016%**		±2% of the flow-weighted mean CO_2 conc. at the standard

Table 2-2 H_2O Interference Check for CO_2

1065.355 H_2O and CO_2 Interference Check for CO NDIR Analyzers.

H_2O and CO_2 can positively interfere with an NDIR analyzer by causing a response similar to carbon monoxide (CO). A CO NDIR analyzer must have combined H_2O and CO_2 interference that is less than 2% of the flow-weighted average concentration of CO expected at the standard, though it is recommended that the interference be less than 1%. This test is conducted by bubbling CO_2 span gas through a water to create a water saturated test gas that creates a response in the NDIR.

1065.355 H_2O and CO_2 interference for CO NDIR [ppm]			
Wet CO_2 Span Gas	0.58945634	ppm	CO conc meas with wet CO_2 span gas
CO_2 Span Conc	3.580%		CO_2 span gas conc
Dew Point	28.47	degC	DP of wet CO_2span gas
Exp. CO_2 Mean Conc.	0.81%		Transient cycle
Ratio CO Conc.	**0.133**	ppm	
CO Mean Conc.	25.4	ppm	1.399
Exp. CO at Standard	281	ppm	15.5
Criteria	**5.6**	ppm	±2% of the flow-weighted mean CO conc at the standard

Table 2-3 H_2O and CO_2 Interference Check for CO

1065.360 FID Optimization (Methane Response).

FIDs respond differently to methane than other hydrocarbons, and this factor must be incorporated into emissions calculations. For this exercise, the response of FID to a methane calibration gas was determined to provide a methane response factor.

	1065.360 FID optimization (methane response)			
	Methane Actual	Measured	CH4 RF	point vs ave
10	104.09	115.16	1.11	0.2%
9	94.40	104.43	1.11	0.2%
8	81.79	90.35	1.10	0.0%
7	71.95	79.43	1.10	0.0%
6	61.18	67.49	1.10	-0.1%
5	51.29	56.57	1.10	-0.1%
4	40.46	44.52	1.10	-0.4%
3	29.73	33.08	1.11	0.8%
2	19.84	21.91	1.10	0.0%
1	14.34	15.76	1.10	-0.5%
	Average		**1.10**	

Table 2-4 FID Methane Response

1065.365 Nonmethane Cutter Penetration Fractions Determination.

A nonmethane cutter removes nonmethane hydrocarbons from the exhaust stream before the FID analyzer measures hydrocarbon concentrations. It is recommended that the nonmethane cutter be optimized by adjusting the catalyst temperature such that the penetration factor for CH_4 is >0.9 while the penetration factor for C_2H_6 is <0.1.

1065.365 Nonmethane cutter penetration fractions [%]		
Ethane Conc.	362	ppmC1
Cutter response	3.568	ppmC1
Ethane penetration fraction	**0.99%**	

Table 2-5 Non-Methane Cutter Penetration Fractions

1065.370 CLD CO_2 and H_2O Quench Check.

H_2O and CO_2 can negatively interfere with a chemiluminescence detector (CLD)'s NO_x response by collisional quenching, which inhibits the chemiluminescent reaction that a CLD utilizes to detect NO_x. The calculations in 1065.672 are used to determine the impact of H_2O and CO_2 in quenching the chemiluminescent signal in a NO span. The procedure and the calculations scale the quench results to the water vapor and CO_2 concentrations expected during testing. A CLD analyzer must have a combined H_2O and CO_2 quench of less than ±2%, though it is recommended that quench be below ±1%. This check is performed by introducing CO_2 into an NO calibration gas and by bubbling an NO calibration gas through water.

1065.370 CO_2 and H_2O quench verification for NO_x CLD [%]			
NO_x wet	245.77	ppm	NO conc with wet NO_x span gas
NO_x dry	259.93	ppm	NO conc with dry NO_x span gas
dewTemp	28.47	C	
satPres at dewTemp	3893.04	Pa	
Local Baro Press	98737.64	Pa	
H_2Omeas	3.94%		H_2O conc of wet NO_x span gas
H_2Oexp	3.50%		Max water conc expected during test
NO, CO_2	129.25	ppm	NO conc with 50% CO_2 span gas and 50% NO_x span gas
NO,N_2	129.84	ppm	NO conc with 50% N2 and 50% NO_x span gas
CO_2meas	3.58%		CO_2 conc with 50% CO_2 span gas and 50% NO_x span gas
CO_2exp	2.50%		Max CO_2 conc expected during test
H_2O Quench	-1.39%		
CO_2 Quench	-0.32%		
Quench	**-1.71%**		

Table 2-6 CO_2 and H_2O Quench Verification for NO_x CLD

1065.378 NO_2 to NO Converter Efficiency Check.

An NO_2 to NO converter allows an analyzer that measures only NO to determine to NO_x by converting NO_2 in exhaust to NO. The converter was found to convert NO_2 to NO with an efficiency of 96.4%.

Linearity Checks

Linearity checks were performed on all analyzers, temperature sensors, pressure sensors, and mass flow controllers (MFCs).

Sensor	**Slope**			**Intercept**			**SEE**			**r^2**			**Overall**	
Name	Value	Criteria	Pass/Fail	Value	Criteria	Pass/Fail	Value	Criteria	Pass/Fail	Value	Criteria	Pass/Fail	Pass/Fail	**Units**
CO	0.999	0.99 / 1.01	Pass	-0.002	1.162	Pass	0.212	1.162	Pass	1.0000	0.998	Pass	Pass	ppm
CO2	1.001	0.99 / 1.01	Pass	-0.004	0.057	Pass	0.006	0.057	Pass	1.0000	0.998	Pass	Pass	%
NOx	1.000	0.99 / 1.01	Pass	-0.234	4.645	Pass	0.365	4.645	Pass	1.0000	0.998	Pass	Pass	ppm
THC	1.000	0.99 / 1.01	Pass	-0.086	2.452	Pass	0.148	2.452	Pass	1.0000	0.998	Pass	Pass	ppm
CH4	1.000	0.99 / 1.01	Pass	-0.094	2.265	Pass	0.178	2.265	Pass	1.0000	0.998	Pass	Pass	ppm
TC_room	tbd													C
TC_Hxout	tbd													C
TC_Hxin	tbd													C
TC_cont	tbd													C
TC_oven	tbd													C
TC_split	tbd													C
TC_filter	tbd													C
T_CVSd	0.999	0.99 / 1.01	Pass	0.067	0.992	Pass	0.035	0.992	Pass	1.0000	0.998	Pass	Pass	C
T_CVSt	0.993	0.99 / 1.01	Pass	-0.125	2.990	Pass	0.208	2.990	Pass	1.0000	0.998	Pass	Pass	C
T_CFO	tbd													C
TC_exh	tbd													C
TC_CVSin	tbd													C
P_CVSt	1.000	0.99 / 1.01	Pass	-0.076	7.622	Pass	0.083	7.622	Pass	1.0000	0.998	Pass	Pass	mmHg
P_CVSd	1.000	0.99 / 1.01	Pass	-0.030	7.622	Pass	0.079	7.622	Pass	1.0000	0.998	Pass	Pass	mmHg
P_amb	1.000	0.99 / 1.01	Pass	-0.003	0.300	Pass	0.004	0.300	Pass	1.0000	0.998	Pass	Pass	inHg
P_CFO	0.996	0.99 / 1.01	Pass	0.057	0.651	Pass	0.019	0.651	Pass	1.0000	0.998	Pass	Pass	psig
dP_CVSt	1.004	0.99 / 1.01	Pass	-0.015	0.500	Pass	0.011	0.500	Pass	1.0000	0.998	Pass	Pass	inH20
dP_CVSd	1.003	0.99 / 1.01	Pass	-0.031	0.500	Pass	0.030	0.500	Pass	1.0000	0.998	Pass	Pass	inH20
dP_Filter	1.001	0.99 / 1.01	Pass	-0.315	2.000	Pass	0.121	2.000	Pass	1.0000	0.998	Pass	Pass	inH20
dP_CVS_stack	1.001	0.99 / 1.01	Pass	0.020	0.200	Pass	0.021	0.200	Pass	1.0000	0.998	Pass	Pass	+/- inH20
dP_CVS_exh	1.001	0.99 / 1.01	Pass	0.476	1.000	Pass	0.338	1.000	Pass	1.0000	0.998	Pass	Pass	inH20
T_RH_amb	1.000	0.99 / 1.01	n/a	0.749	0.722	n/a	1.070	0.722	n/a	0.9990	0.998	n/a	n/a	RH
T_RH_cond	1.000	0.99 / 1.01	n/a	0.902	0.714	n/a	1.104	0.714	n/a	0.9990	0.998	n/a	n/a	RH
T_dew	1.001	0.99 / 1.01	Pass	0.586	3.012	Pass	0.595	3.012	Pass	0.9993	0.998	Pass	Pass	K
Speed	tbd													mph
MFC41	1.005	0.99 / 1.01	Pass	-0.352	1.027	Pass	0.315	1.027	Pass	0.9999	0.998	Pass	Pass	sccm

MFC42	1.000	0.99 / 1.01	Pass	0.000	0.010	Pass	0.001	0.010	Pass	1.0000	0.998	Pass	Pass	slpm
MFC43	0.999	0.99 / 1.01	Pass	0.003	0.098	Pass	0.005	0.098	Pass	1.0000	0.998	Pass	Pass	slpm
MFC44	1.001	0.99 / 1.01	Pass	-0.001	0.017	Pass	0.002	0.017	Pass	1.0000	0.998	Pass	Pass	slpm
MFC45	1.001	0.99 / 1.01	Pass	0.009	0.286	Pass	0.051	0.286	Pass	1.0000	0.998	Pass	Pass	slpm
MFC46	0.998	0.99 / 1.01	Pass	0.000	0.048	Pass	0.011	0.048	Pass	1.0000	0.998	Pass	Pass	slpm
MFC47	0.998	0.99 / 1.01	Pass	0.077	0.285	Pass	0.085	0.285	Pass	1.0000	0.998	Pass	Pass	slpm 20C 1 atm
MFC61	1.001	0.99 / 1.01	Pass	-0.130	1.081	Pass	0.185	1.081	Pass	1.0000	0.998	Pass	Pass	slpm
MFC62	1.000	0.99 / 1.01	Pass	-0.083	1.059	Pass	0.195	1.059	Pass	1.0000	0.998	Pass	Pass	slpm
MFC63	1.000	0.99 / 1.01	Pass	0.003	0.273	Pass	0.045	0.273	Pass	1.0000	0.998	Pass	Pass	slpm
MFC64	1.002	0.99 / 1.01	Pass	-0.012	0.269	Pass	0.065	0.269	Pass	1.0000	0.998	Pass	Pass	slpm
MFC65	1.000	0.99 / 1.01	Pass	-0.006	0.282	Pass	0.029	0.282	Pass	1.0000	0.998	Pass	Pass	slpm
MFC66	1.001	0.99 / 1.01	Pass	0.005	0.068	Pass	0.019	0.068	Pass	1.0000	0.998	Pass	Pass	slpm
MFC67	1.000	0.99 / 1.01	Pass	-0.002	0.016	Pass	0.003	0.016	Pass	1.0000	0.998	Pass	Pass	slpm
MFC68	1.004	0.99 / 1.01	Pass	-0.091	0.527	Pass	0.115	0.527	Pass	1.0000	0.998	Pass	Pass	slpm
MFC69	1.001	0.99 / 1.01	Pass	-0.049	0.521	Pass	0.095	0.521	Pass	1.0000	0.998	Pass	Pass	slpm

Standard conditions at 20C, 1 atm

2.3 CARB Audit Bottle Comparisons

CARB staff from El Monte did some cross checks of the CE-CERT analyzers with calibration bottles that they provided. These audit bottles showed some differences slightly greater than 2% for CO and NO_x. The reason for the high audit response was that a new purge process was being implemented that at the time did not provide sufficient stabilization time. The implementation of the purge process was completed by the time testing was conducted at SwRI and included longer purge times. The audit bottle cross calibrations made at SwRI did not indicate any further issues. The longer purge times improved the stabilization for CO and NO_x by approximately 1 ppm.

UCR CE-CERT MOBILE LABORATORY - JUNE 2006 TEST RESULTS:

TYPE OF ANALYZERS CALIFORNIA ANALYTICAL INSTRUMENT

(NIST) REFERENCE GAS	CYLINDER I.D.	REF. Conc. ppm	LAB. Conc. ppm	CONC. Difference %	LAB. Span Value	ANALYZER Range ppm/%
C3H8	FF28567	8.646	8.57	-0.88	94.70	100
		8.646	8.67	0.28	94.70	100
CO	CAL011764	25.05	24.40	**-2.59**	94.60	100
	XF000386B	48.76	47.60	**-2.38**	94.60	100
CO_2	CAL013669	0.4795	0.478	-0.31	3.72	4%
	CAL013725	0.9710	0.966	-0.51	3.72	4%
NO_x	CAL015570	48.52	47.40	**-2.31**	202.00	250

Table 2-7 CARB Audit Bottle Checks

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3.0 Cross Correlation Testing with SwRI and CE-CERT

A complete cross-laboratory correlation was conducted between the CE-CERT MEL and an engine dynamometer laboratory at the Southwest Research Institute (SwRI) in San Antonio, TX. The CE-CERT MEL was towed to the SwRI facility in San Antonio, TX from Riverside, CA for this testing, such that the testing was conducted side-by-side. This exercise was carried out prior to the on-road testing of the PEMS to ensure comparability of the on-road measurements with those collected in the main engine dynamometer testing portion of the Measurement Allowance program.

3.1 Experimental Procedures

The cross correlation exercise was performed at SwRI at the engine dynamometer facility being used for the engine testing portion of the Measurement Allowance program. A 2005, 14 liter Detroit Diesel Series 60 engine was used as the test engine. This was one of the three test engines being used by SwRI on the main engine testing portion of the Measurement Allowance program. The CE-CERT MEL was positioned external to the engine laboratory and the transfer tube was routed from the engine cell to the MEL.

Emissions testing was conducted using two cycles, an NTE engine cycle, which is an engine cycle that was designed for the main portion of the engine testing, and the Ramped Modal cycle (RMC). For each day of testing, three iterations of the NTE cycle and two iterations of the Ramped Modal cycle were performed using each of the emissions analyzer benches, i.e., the SwRI emissions benches for the test cell and the CE-CERT MEL. The order of testing for the SwRI emissions equipment and the MEL was reversed on alternating test days. For the first day testing was performed using the SwRI emissions benches followed by the MEL. For the second day of testing, this order was reversed so that testing was conducted on the MEL followed by the SwRI emissions benches. For the final day, the SwRI emissions benches were used first followed by the MEL benches.

After the arrival of the CE-CERT MEL, but prior to the emissions test, a full calibration of system analyzers and a propane recovery test were conducted with the MEL. This included cross calibration of the SwRI and MEL with calibration bottle from the other laboratory. After arrival at the SwRI facility, there was a failure with a computer board related to the MEL dilution tunnel. This board was replaced prior to testing and propane recovery checks showed the dilution tunnel was operating with no issues.

3.2 Calibration Bottle Results

Cross correlations between the CE-CERT and SwRI audit bottle were conducted prior to beginning testing. The CE-CERT MEL audit bottle results are provided in Table 3-1. The audit bottles included a THC bottle and a combination CH_4, CO, NO_x, and CO_2 bottle from CE-CERT, and two NO_x and one CO_2 concentration bottle from SwRI. Comparison of the measurements with the audit bottle standard concentrations indicated that all measurements were within 2% of the audit bottle concentrations, with all but a few CO_2 measurements within 1%.

File Name		Measured					Bottle Primary Standard					Percent Deviation from Standard					
	Bottle	THC	CH_4	CO	NO_x	pCO_2	THC	CH_4	CO	NO_x	CO_2	THC	CH_4	CO	NO_x	pCO_2	
n/a	Supplier	ppm	ppm	Ppm	ppm	%	ppm	ppm	ppm	ppm	%						
200506010933	CECERT	184.57					185.15					-0.3%					
200505091012	CECERT		9.266	91.22	100.2	1.536		9.27	90.6	100	1.554		0.0%	0.7%	0.2%	-1.2%	*
200506010933	SwRi				27.16					27.08					0.3%		*
200506010940	SwRi					1.784					1.815					-1.7%	*
200506211255	SwRi				88.03					87.45					0.7%		*
200506211255	CECERT		9.292	91.03	100.4	1.532		9.27	90.6	100	1.554		0.2%	0.5%	0.4%	-1.4%	*
200506291452	CECERT		9.266	91.22	100.2	1.555		9.27	90.6	100	1.554		0.0%	0.7%	0.2%	0.1%	**
200506291459	SwRi				27.2					27.08					0.3%		**
200506291452	SwRi					1.802					1.815					-0.7%	**
200506291459	SwRi				88.0					87.45					0.7%		**
200508120923	CECERT		9.292	91.03	100.4	1.554		9.27	90.6	100	1.554		0.2%	0.5%	0.4%	0.0%	**

* = uncorrected CO_2 curve; ** = linearized CO_2 typical calibration

Table 3-1 CE-CERT MEL Audit Bottle Results

3.2 Correlation Testing Results

Overall, the MEL showed good correlation with the emissions measurements made in the SwRI test cell. A summary of the results is provided in Table 3-2 for the NTE cycle and Table 3-3 for the RMC. For the NTE emissions cycle, the MEL was 2.1% higher than the SwRI measurement for NO_x and 2.7% higher than SwRI for CO_2. For the RMC, the MEL was approximately 3.8% higher than the SwRI measurement for NO_x and 2.3% higher than SwRI for CO_2. THC and CO emissions were at relatively low levels and showed larger deviations (-65 to -92% for THC and -16 and -24% for CO). These results were reviewed with the MASC and it was agreed they were acceptable for the measurement allowance program.

Test Day	Test Date	Test Number	Transient Emissions, g/hp-hr					
			THC	CH_4	NMHC	CO	NO_x	CO_2
1	6/29/2006	SwRI-NTE-1	0.003	-0.005	0.008	0.057	1.99	540.4
1	6/29/2006	SwRI-NTE-2	0.003	0.001	0.002	0.057	1.97	540.9
1	6/29/2006	SwRI-NTE-3	0.004	0.003	0.001	0.057	1.99	542.0
		Mean	**0.003**	**0.000**	**0.004**	**0.057**	**1.98**	**541.1**
1	6/29/2006	CE-CERT-NTE-1	0.001	0.001	-0.001	0.044	2.03	557.6
1	6/29/2006	CE-CERT-NTE-2	0.001	0.002	-0.001	0.044	2.03	558.0
1	6/29/2006	CE-CERT-NTE-3	0.001	0.002	-0.001	0.042	2.04	557.8
		Mean	**0.001**	**0.002**	**-0.001**	**0.043**	**2.03**	**557.8**
		Day 1 Difference (%point)	**-288%**	**119.7%**	**546.0%**	**-31.7%**	**2.4%**	**3.0%**
2	6/30/2006	SwRI-NTE-1	0.004	0.001	0.003	0.058	2.04	541.5
2	6/30/2006	SwRI-NTE-2	0.003	0.002	0.001	0.054	2.01	543.0
2	6/30/2006	SwRI-NTE-3	0.003	0.002	0.001	0.057	2.02	542.4
		Mean	**0.003**	**0.002**	**0.002**	**0.056**	**2.02**	**542.3**
2	6/30/2006	CE-CERT-NTE-1	0.002	0.001	0.000	0.041	2.04	554.2
2	6/30/2006	CE-CERT-NTE-2	0.001	0.002	-0.001	0.040	2.05	551.7
2	6/30/2006	CE-CERT-NTE-3	0.001	0.002	-0.001	0.041	2.04	551.1
		Mean	**0.001**	**0.002**	**0.000**	**0.041**	**2.04**	**552.3**
		Day 2 Difference (%point)	**-148.3%**	**8.2%**	**556.3%**	**-38.2%**	**1.0%**	**1.8%**
3	7/5/2006	SwRI-NTE-1	0.005	-0.007	0.012	0.055	2.01	539.5
3	7/5/2006	SwRI-NTE-2	0.003	0.002	0.001	0.052	1.99	540.4
3	7/5/2006	SwRI-NTE-3	0.003	0.002	0.001	0.053	2.00	541.2
		Mean	**0.004**	**-0.001**	**0.005**	**0.053**	**2.00**	**540.4**
3	7/5/2006	CE-CERT-NTE-1	0.001	0.002	-0.001	0.042	2.06	558.5
3	7/5/2006	CE-CERT-NTE-2	0.001	0.002	-0.001	0.043	2.05	558.0
3	7/5/2006	CE-CERT-NTE-3	0.002	0.002	0.000	0.042	2.07	554.8
		Mean	**0.001**	**0.002**	**-0.001**	**0.042**	**2.06**	**557.1**
		Day 3 Difference (%point)	**-159.4%**	**152.1%**	**960.2%**	**-26.2%**	**2.9%**	**3.0%**
Standard for 2005 DDC Series 60 Engine			0.14	0.14	0.14	15.5	2.2	
NTE	SwRI	Mean	0.004	0.000	**0.004**	**0.056**	**2.001**	541.3
		Stdev	0.001	0.004	0.004	0.002	0.020	1.1
	CE-CERT	Mean	0.001	0.002	**-0.001**	**0.042**	**2.044**	555.7
		Stdev	0.000	0.000	0.000	0.001	0.014	2.9
		%point	-65.1%	2336.2%	**-117.4%**	**-24.2%**	**2.1%**	**2.7%**
		%standard	-1.6%	1.3%	**-2.9%**	**-0.1%**	**1.9%**	n/a

Table 3-2 Correlation Results Between SwRI and CE-CERT MEL – NTE Engine cycle

Test Day	Test Date	Test Number	Transient Emissions, g/hp-hr					
			THC	CH_4	NMHC	CO	NO_x	CO_2
1	6/29/2006	SwRI-RMC-1	0.004	0.000	0.004	0.054	1.79	499.8
1	6/29/2006	SwRI-RMC-2	0.003	0.002	0.001	0.057	1.80	499.8
		Mean	**0.004**	**0.001**	**0.003**	**0.055**	**1.80**	**499.8**
1	6/29/2006	CE-CERT-RMC-1	0.000	0.001	-0.002	0.048	1.88	511.7
1	6/29/2006	CE-CERT-RMC-2	0.000	0.001	-0.001	0.052	1.88	510.5
		Mean	**0.000**	**0.001**	**-0.002**	**0.050**	**1.88**	**511.1**
		Day 1 Difference (%point)	**-109%**	**23%**	**-160%**	**-9.5%**	**4.6%**	**2.3%**
2	6/30/2006	SwRI-RMC-1	0.002	0.000	0.002	0.054	1.83	500.6
2	6/30/2006	SwRI-RMC-2	0.002	0.000	0.002	0.053	1.84	501.1
		Mean	**0.002**	**0.000**	**0.002**	**0.053**	**1.84**	**500.8**
2	6/30/2006	CE-CERT-RMC-1	0.001	0.002	-0.001	0.043	1.90	508.1
2	6/30/2006	CE-CERT-RMC-2	0.000	0.002	-0.001	0.041	1.91	509.0
		Mean	**0.001**	**0.002**	**-0.001**	**0.042**	**1.90**	**508.5**
		Day 2 Difference (%point)	**-72%**	**1586%**	**-161%**	**-21%**	**3.6%**	**1.5%**
3	7/5/2006	SwRI-RMC-1	0.002	0.002	0.000	0.052	1.84	498.9
3	7/5/2006	SwRI-RMC-2	0.002	0.002	0.001	0.052	1.85	499.0
		Mean	**0.002**	**0.002**	**0.000**	**0.052**	**1.85**	**499.0**
3	7/5/2006	CE-CERT-RMC-1	0.000	0.002	-0.002	0.041	1.92	514.2
3	7/5/2006	CE-CERT-RMC-2	0.000	0.001	0.000	0.045	1.89	514.6
		Mean	**0.000**	**0.001**	**-0.001**	**0.043**	**1.91**	**514.4**
		Day 3 Difference (%point)	**-84%**	**-35%**	**-314%**	**-17%**	**3.2%**	**3.1%**
Standard for 2005 DDC Series 60 Engine			0.14	0.14	0.14	15.5	2.2	
Overall Results RMC Cycle								
RMC	SwRI	Mean	0.003	0.001	**0.002**	**0.053**	**1.827**	499.9
		Stdev	0.001	0.001	0.001	0.002	0.024	0.9
	CE-CERT	Mean	0.000	0.002	**-0.001**	**0.045**	**1.897**	511.3
		Stdev	0.000	0.001	0.001	0.004	0.015	2.7
		% of Point	-92.6%	42.9%	**-171.9%**	**-16%**	**3.8%**	**2.3%**
		% of Standard	-1.8%	0.3%	**-2.1%**	**-0.1%**	**3.1%**	n/a

Table 3-3 Correlation Results Between SwRI and CE-CERT MEL – Ramped Modal cycle

4.0 On-Road Testing of PEMS vs. CE-CERT MEL – Experimental Procedures

Comparisons were made between the CE-CERT MEL and the PEMS under in-use conditions designed to generate NTE events and provide a variety of conditions such as temperature, elevation, etc. The experimental procedures and test routes are described in this section.

4.1 Test Vehicle

The test truck for the on road testing was provided by Caterpillar. The truck was equipped with a 475 hp Caterpillar C-15 ACERT engine with 200 hours or about 5,000 miles on it since being rebuilt. The engine was certified to the 2.5 g/bhp-hr NO_x + NMHC and 0.1 g/bhp-hr PM standard. The engine was equipped with dual exhausts and originally had a pair of oxidation catalysts. In order to achieve emissions levels representative of 2007 standards, the oxidation catalysts were removed and were replaced with a diesel particulate filter (DPF). The DPF was provided by International Truck and Engine Corp. and had an effective volume of 1391.6 in^3, which was deemed to provide sufficient capacity for the test engine. The DPF was configured to meet the Caterpillar specifications for recommended back pressure with DPF installed of 35 – 50 inches. Preliminary on-road tests showed that the measured back pressure with the DPF installed was approximately 45 inches at high speed/high loads, with the back pressure measured 12 inches from turbo and 3 feet before the DPF. The DPF installation is shown in Figure 4-1.

Figure 4-1. Installation of Diesel Particulate Filter

4.2 PEMS Operation

A SEMTECH DS PEMS unit was used for the on-road testing. This is the same model being used for the main portion of the engine and environmental testing at SwRI, and this specific unit was used for a segment of the environmental testing at SwRI prior to being shipped to CE-CERT. A description of the PEMS is provided in Appendix B.

The PEMS was utilized in two different locations for the on-road testing, one inside the cab and one outside the cab. Pictures of the in and out of cab installation are shown below in Figures 4-2 and 4-3, respectively. The in cab runs were performed with the PEMS placed on the aluminum flooring of the air ride cab. The out of cab runs were performed with the PEMS mounted in a frame that was specially constructed behind the driver side fuel tank. The Sensors Inc. environmental case was used for the out of cab testing as pictured in Figure 4-3, whereas the case was not used for the in cab installation.

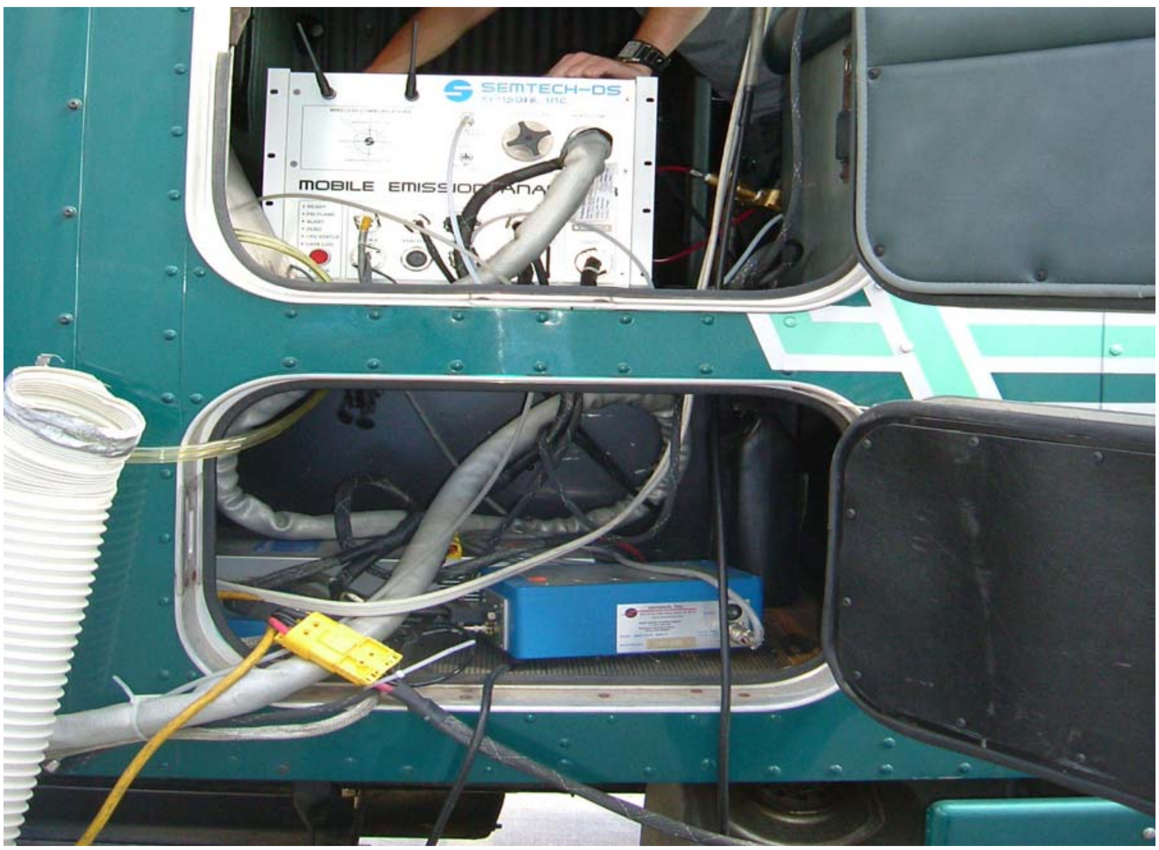


Figure 4-2 Picture of In Cab PEMS Installation

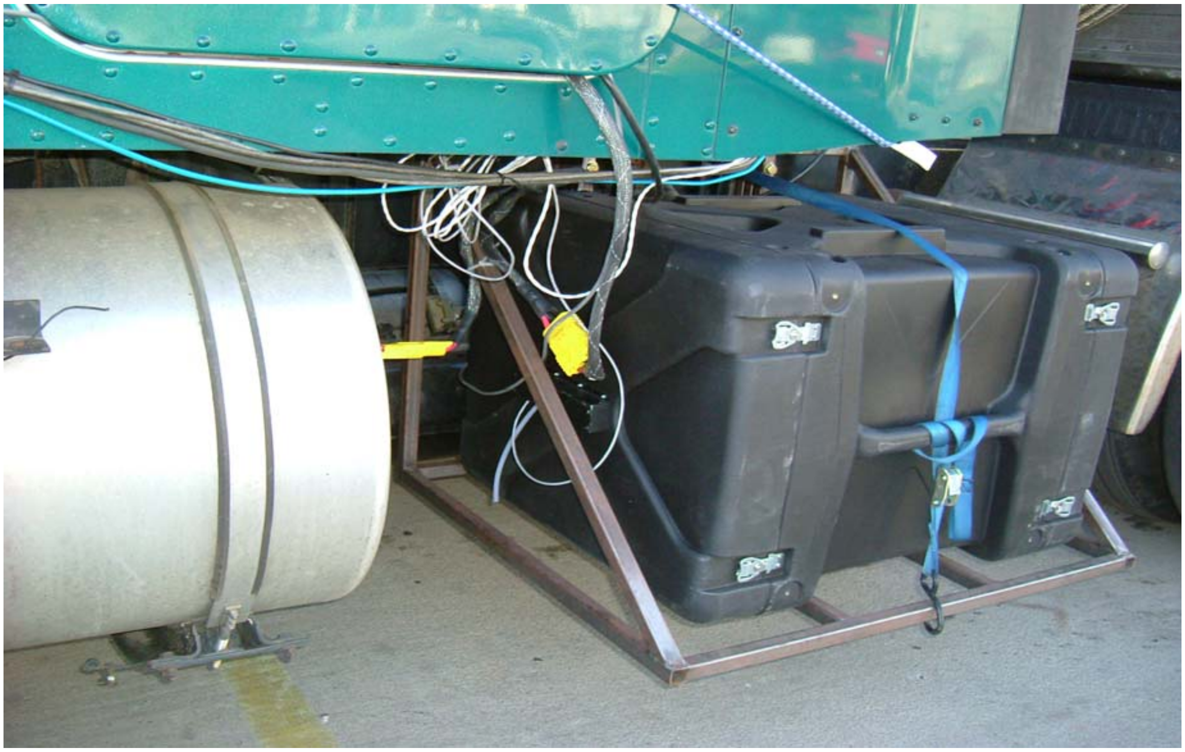


Figure 4-3 Picture of Out-of-Cab PEMS Installation

The set up included the installation of the flow meter, sample lines, and required sensors for the PEMS. The flow monitoring and sample probe was installed in roughly the middle of a straight pipe section leading from the end of the exhaust towards the dilution tunnel. The sample probe and exhaust flow meter (EFM) were installed approximately 10 exhaust pipe diameters (50 inches) after the final exhaust hookup to ensure full mixing prior to the sample point. This point was not originally specified in the manual but was agree to following subsequent conversations with the steering committee. An additional straight section of 6 exhaust pipe diameters was also added after the sample probe prior to the dilution tunnel. A picture of the exhaust connection is provided in Figure 4-4. The relative humidity (RH) sensor was mounted vertically on the outside the cab on the driver's side, as shown in Figure 4-5. The use of a UV or weather shield on the RH sensor was discussed with the steering committee prior to the on-road tests, since the PEMS manual provides some flexibility on when the shield is or is not need. Based on this discussion, it was decided not to employ the weather shield during the on-road testing. During testing the RH ambient temperature seemed higher than other ambient temperature measurements. The post calculated humidity correction factors also showed differences between the MEL and PEMS. As such, for the final calculations the temperature and humidity corrections for the MEL were used for both the MEL and the PEMS. A standard 104 liter FID fuel bottle, typical of that used with this particular PEMS was used. The PEMS was loaded with the Lug Curve used in previous tests with this same C15 engine. The ECM module was set up for J1939 and a GPS for the PEMS was installed.

Figure 4-4. Picture of Exhaust Connection for PEMS

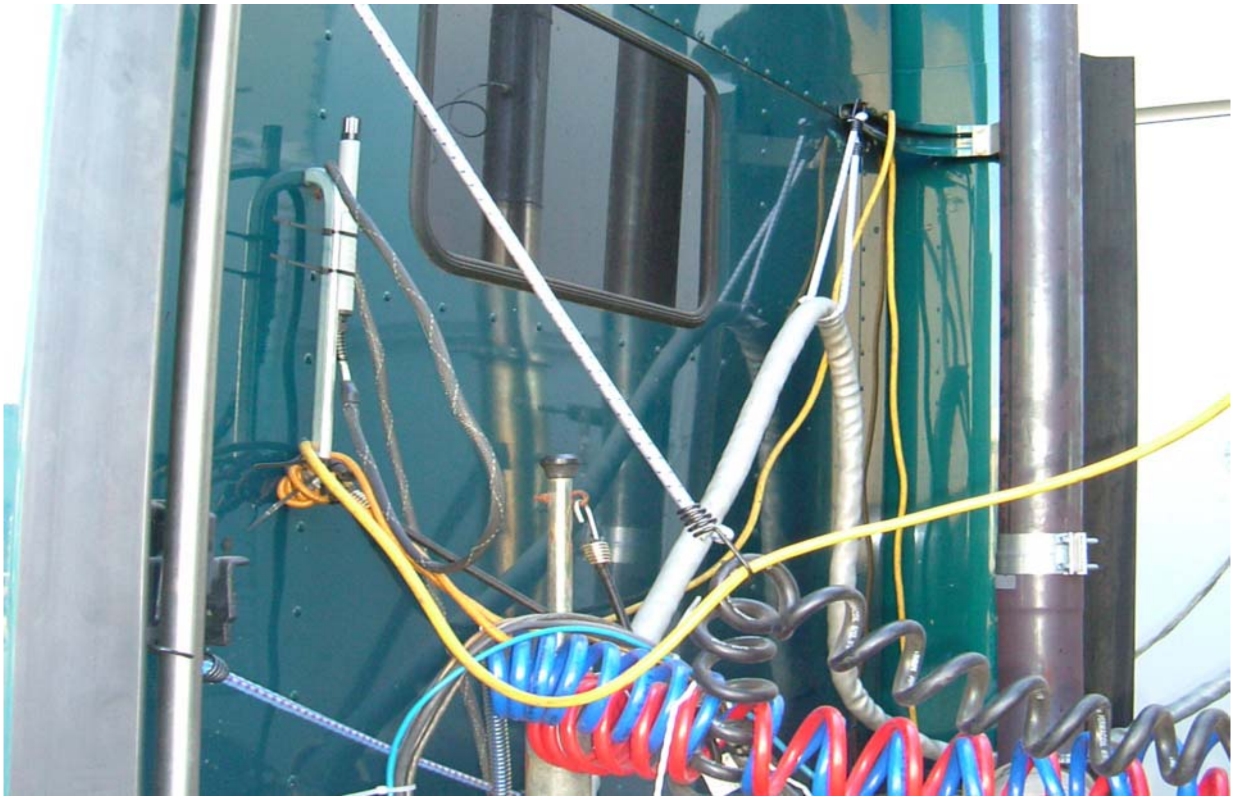


Figure 4-5. Installation of Relative Humidity Sensor

Prior to beginning the on-road testing, a representative of Sensors Inc. visited CE-CERT and provided one day of training. Although several CE-CERT staff were already familiar with the general Semtech operation, the additional day of training provided assurances that the instrument was operated properly and that CE-CERT staff were current on the latest software and hardware with the Semtech DS system. The newest version of software that was available at the time of testing (version 10.05SP2) was used during the testing.

The PEMS was operated in a manner consistent with the manufacturers manual and the procedures being used by SwRI, except for some changes to facilitate on-road testing in conjunction with the MEL. The PEMS is typically operated in auto-zero and auto-exhaust flow meter (EFM) purge mode. The PEMS automatic procedures were turned off to facilitate the MEL triggering automatically. CE-CERT staff manually zeroed and purged the EFM at the end of each 50 minute sample period. The zero calibration and EFM purge were performed while progressing through the routes at the flow of traffic or in local conditions such as waiting in truck scales or at traffic lights. In the event of a 10 minute delay to start the next test cycle, a zero and EFM purge were performed prior to starting the next test segment to capture the data within an approximate one hour zero calibration and EFM purge.

In order to maintain data integrity and clarity of file names, CE-CERT chose to operate the PEMs using the session manager available in the supplied software. Each session was set up using the route name and each test was identified by the MEL test name. The MEL test name is number representing year, month, day, hour, and minute (i.e., 200611051232 is year 2006, month 11, day 05, hour 12, and minute 32). The session manager was successful on all tests except the first day in-cab Route 1. The session manager was not utilized during that test because the test was performed prior to identifying this particular feature of the software. The session manager has the advantage of maintaining pre- and post-zero drift information and pre- and post-audit calibrations. A list of the raw XML (Extensible Markup Langauge) file names is listed in Appendix C. The table of file names describes all the details of that test segment and any issues or details regarding that data set.

One other operational difference was FID bottle changes. The committee decided to change the FID fuel bottle when the pressure was below 300 psi. The bottle pressure was checked before starting each test segment. If the bottle pressure was less than 300 psi the bottle was changed. If the pressure was greater than or equal to 300 psi, the next one hour segment would be started. If a bottle change occurred in the middle of a route, CE-CERT performed a zero, span, and audit before and after the bottle change. CE-CERT experienced three mid-bottle changes on the first three in-cab routes. During a bottle change on Route 1 in-cab, the PEMS software froze and CE-CERT was unable to perform a post zero, span, and audit calibration. CE-CERT adapted by selecting bottles above 1700 psi to prevent bottle changes during a test. For all the out-of-cab tests, there were no in-test bottle changes during the entire route.

CE-CERT started the PEMS from cold start conditions each day. A cold start is defined where the PEMS is turned on after being left off over night. CE-CERT staff turned on the PEMS and waited for the ready status indication from the software before beginning calibration. Warm-up is completed when all heater temperatures meet PEMs tolerances and the red status lights turn green. The in-cab PEMS power supply was connected directly to the truck's alternator and not the batteries. On Route 3, the in-cab test PEMs unit took approximately 2 hours to warm up because the ambient temperature was cold and the supply voltage to the power inverter was low, around 13 volts. All in-cab tests were performed with the power supplied by the vehicle.

For the out-of-cab installation, CE-CERT initially moved the power supply from the alternator to the battery pack. The power supply voltage dropped from 13 volts to 12.6 volts at idle. At this voltage, the heaters could not reach tolerances even after two hours. The steering committee and PEMS manufacture recommended connecting the power supply to the MEL generator for out-of-cab correlation tests. All the out-of-cab routes were operated with power supplied by the MEL generator and there were no further issues in warming up the PEMS with this configuration.

Once the PEMS system warmed up, CE-CERT performed a zero, span, and audit check on all systems. If the audit check failed, the zero and span were repeated until the audit passed. The PEMS failed the audit check a few times. It only took one calibration repeat to pass the audit during the correlation exercise. All zero calibrations were performed on ambient air throughout all the routes for both in-cab and out-of-cab installations. At the end of each day a final zero, span and audit were performed. During the post calibration on the Route 3 out-of cab test, CE-CERT performed the standard zero calibration then did an audit check before the span calibration. It was found that many of the gas concentrations were out of tolerance. The final calibration was performed with the audit check and the post calibration audit met all the tolerances.

4.3 MEL Operation

The MEL was operated using procedures similar to those used at SwRI correlation. A standard zero span calibration was performed every hour and before each test throughout the correlation. An audit was performed once each day to verify proper calibration operation. All daily audit checks were within 2% of point throughout the on-road testing program. The MEL did not fill or analyze bags for ambient level concentrations. The steering committee decided to use default ambient concentrations for background corrections. The default concentrations came from averages from the audits for each route. Details can be found in the ambient audit data section. Average ambient concentrations from Route 1 were used on Route 1 and averages from Routes 2 and 3 were used on Routes 2 and 3.

Since the MEL system triggered the PEMS, the order of testing went as follows. First the MEL and PEMS were calibrated and verified. Then the PEMS session manager was started using the route name. Next, the MEL was initiated and a file name was generated. Then the PEMS test segment was started using the MEL file name. Then the MEL was started with a control button available to the driver in the cab. When the button was pressed, a data flag was set and the MEL triggered the PEMS start-sampling flag. The MEL had a specific countdown where both the PEMS and MEL stop flags were set at the end of the 50 minutes. At the end of the test, the PEMS was manually calibrated and the MEL performed a zero and span calibration. The PEMS unit was typically ready two minutes earlier than the MEL. At the end of each sequence, the process was repeated until the end of the route. PM was not measured by the MEL for these on-road tests segments.

A complete audit run was performed over each of the test routes prior to the on-road tests with the PEMS. The audit runs included sampling of audit gases and ambient background. The audit runs included repeat runs alternating sampling of ambient and audit gases. The sequence consisted of 60 seconds of stabilization with ambient air followed by 510 seconds of sampling and measurement of ambient air followed by 30 seconds of stabilization with audit gases followed by 30 seconds of sampling and measurement of audit gases. For each test segment, this sequence was repeated five times for approximately 1 hour. The test segments were then repeated over the course of each route. A zero and span was performed between each test segment.

Figure 4-6. Driver's Aid

Route 1 – Riverside to San Diego Round Trip

The first route for the on-road testing consisted of driving from Riverside to San Diego and then returning to Riverside. This route utilizes Interstate-15 (I-15) and I-5, which are two of California's major freeways. Driving on this route is more rural with possible congestion around the San Diego region and around the Riverside area on the return trip. This route also included some power line crossings and potholes which contributed to road vibrations. This route has many elevation changes, which ensured sufficient generation of NTE events, due to uphill grades that caused the engine to operate in the NTE zone for long periods of time. The total trip distance is approximately 200 miles. The actual trip driving began at approximately 9 AM and went to approximately 1 PM.

The environmental conditions for route 1 are provided in Figure 4-7 for the two test runs. The temperature ranged from approximately 65°F in morning to 87°F in mid day. The elevation extends from approximately 1500 feet (ft.) to down to sea level, with some elevation changes along the route. A map of the route is provided in Figure 4-8.

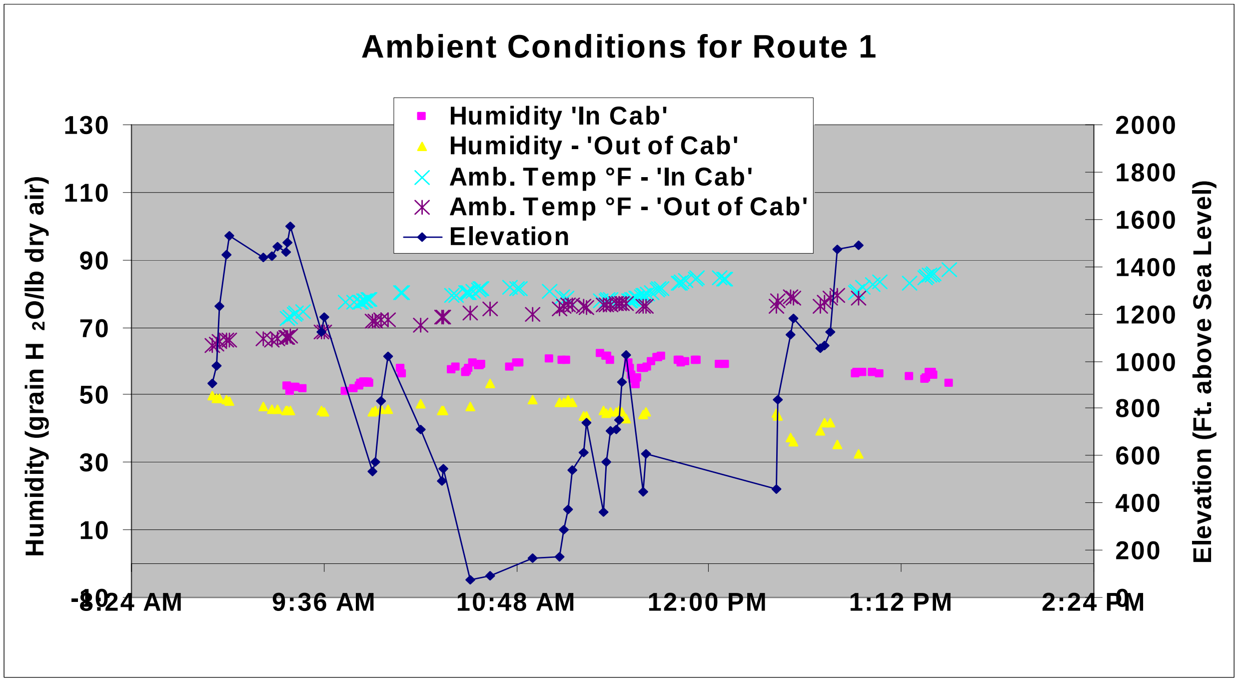


Figure 4-7. Environmental Conditions for Testing along Route 1.

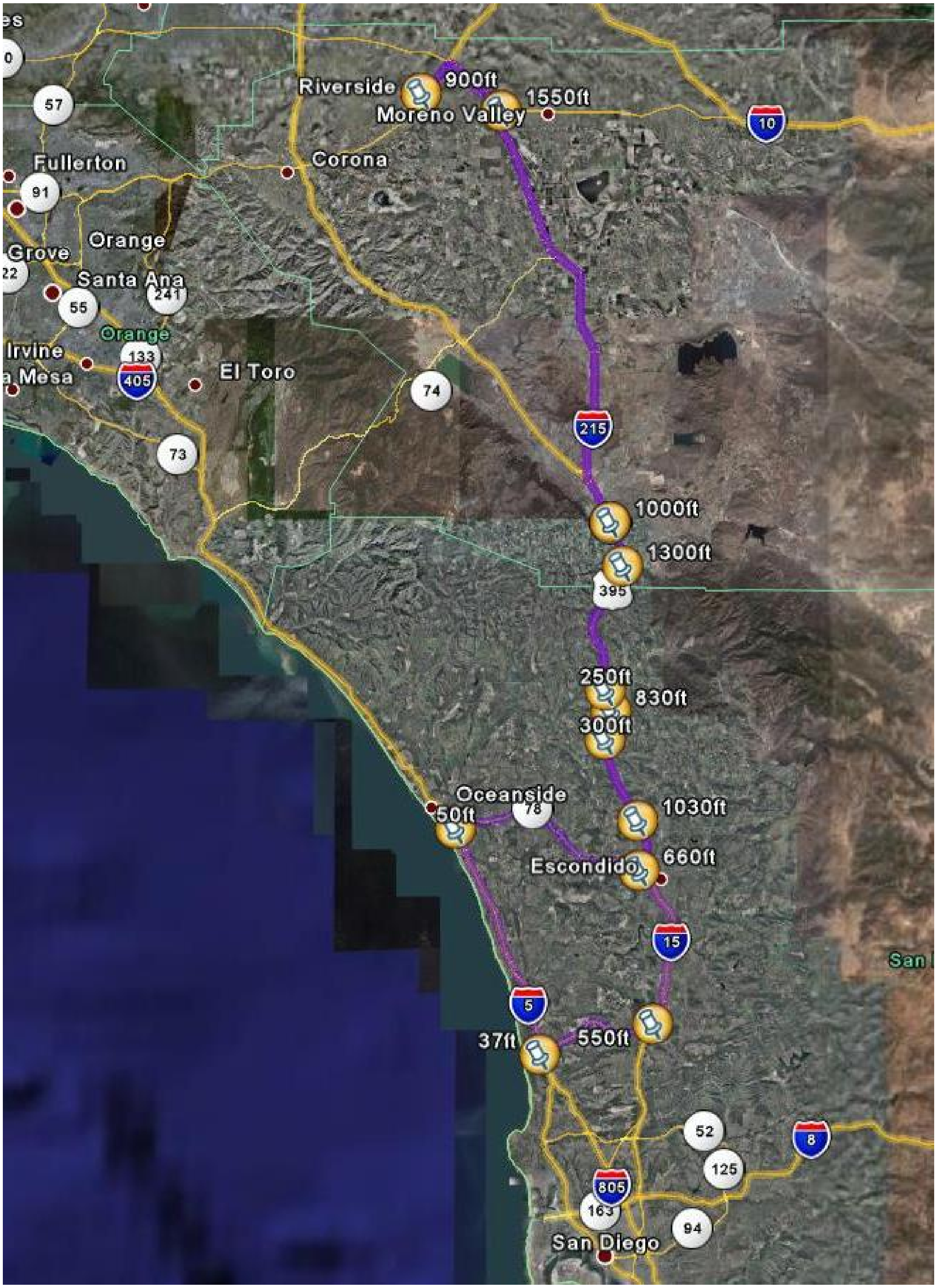


Figure 4-8. Route 3: Riverside to San Diego round trip – distance 197 miles.

Route 2 – Riverside, CA to Bishop/Mammoth Mountain, CA

The second route consisted of driving from Riverside to Bishop/Mammoth Mountain, CA. This route is mostly rural driving along US-395 with some driving on the I-15 at the start of the route. A map of the route is provided in Figure 4-9. Parts of this route carry a significant amount of truck traffic in California. The route has many elevation changes, which created a sufficient number of NTE events, and reaches an elevation above 5000 feet. One section of the road also has high power transmission lines to provide some measure of EMF interference, as shown in Figure 4-10. One railroad crossing provided some measure of road vibration over the route, as shown in Figure 4-11. The total trip distance is approximately 300 miles. Testing was conducted between approximately 9:30 AM and 5 PM on the test day.

The environmental conditions for route 2 are provided in Figure 4-12 for the two test runs. The temperature ranged from 67°F in morning to 88°F in midday and then started to cool back down to the high 70s/low 80s. The elevation extended from approximately 1000 ft. to above 5000 ft. and was generally up hill for a majority of the route. The route included a climb out of Bishop to Mammoth Mountain to ensure the 5000 ft elevation was reached.

Figure 4-9. Route 2,3: Riverside to Mammoth Mountain via US 395.

Figure 4-10. EMF Interference During Routes 2/3

Figure 4-11. Railroad Crossing During Route 2/3

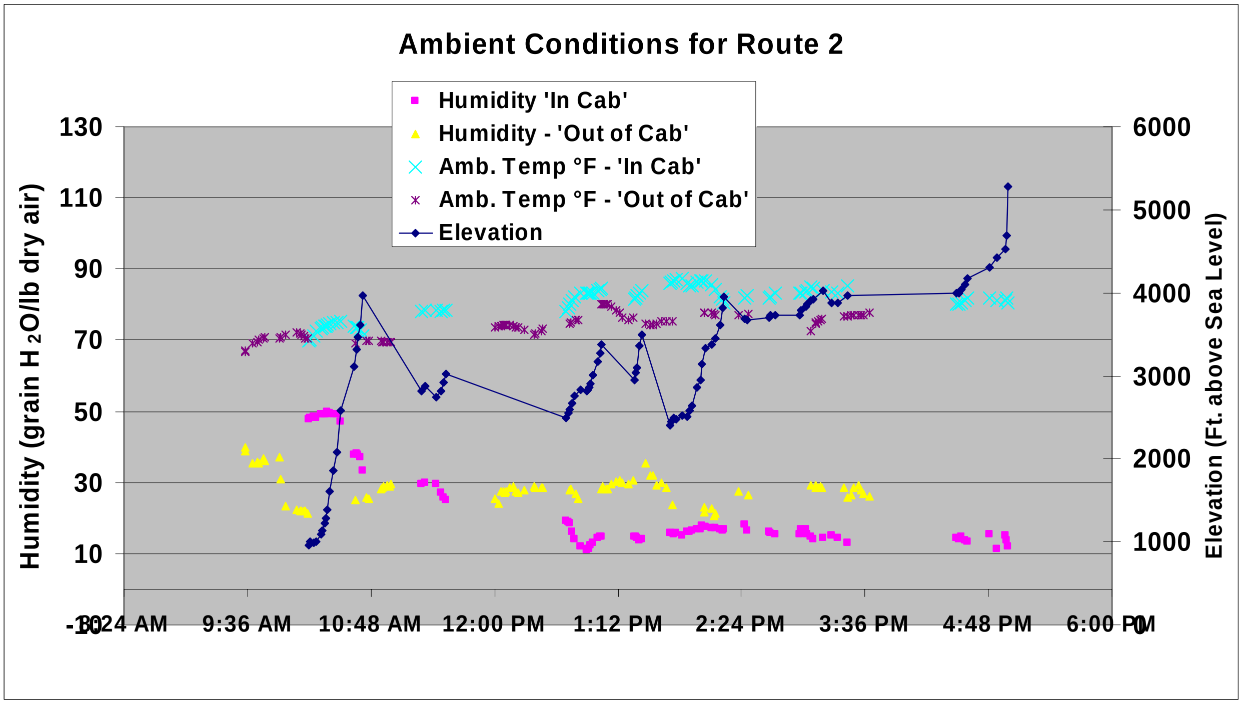


Figure 4-12. Environmental Conditions for Test Runs over Route 2

Route 3 – Return trip from Bishop/Mammoth Mountain, CA to Riverside, CA

The third route is the return trip from Bishop/Mammoth Mountain, CA to Riverside, CA (see Figure 4-9). This route is mostly downhill driving along the I-395 starting from an elevation of approximately 5000 ft., repeating the course for route 2. In the early morning, an extra climb out of Bishop at 4500 ft. towards Mammoth Mountain to above 5000 ft. was performed to provide information under low ambient temperature conditions and corresponding elevation information. The environmental conditions for route 3 are provided in Figure 4-13 for the two test runs. The temperature ranged from just below 50°F in morning to the high 70s/low 80s near the mid day end of the run. The elevation extends from approximately 5000 ft. to approximately 1000 ft. and is generally downhill for a majority of the route. Testing was conducted between approximately 6-7 AM and 1-2 PM on the test day.

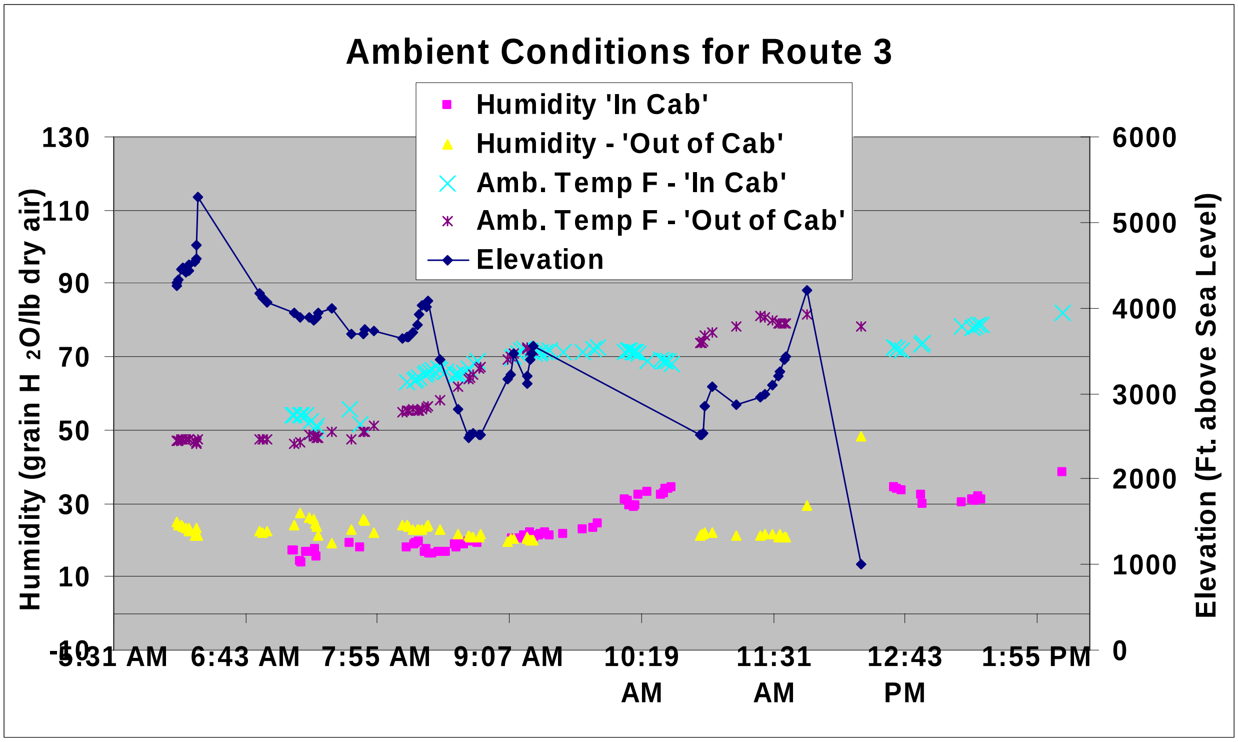


Figure 4-13 Local temperature and RH data near Mammoth Mt.

5.0 On-Road Testing of PEMS vs. CE-CERT MEL – Experimental Results

A total of 6 test runs and 3 audits runs were conducted for the on-road testing. The runs included a trip to San Diego, CA and back, a trip from Riverside to Bishop, CA, and a trip returning to Riverside from Bishop, CA. The trips were conducted with the PEMS positioned inside the cab, with the PEMS positioned outside the cab, and as an audit run without the PEMS.

5.1 Audit Run Results

CE-CERT performed audit tests over the selected routes using three different quad blend audit bottles for CH_4, CO, NO and CO_2 and one single blend for THC. See Table 5-1 for audit blends and calibration set points. The reason multiple audit blends were used was a result of the analyzer consumption rate and the 20 hour duration to run all three routes. One bottle was consumed on each route for the quad species sample stream. For NO_x and CO_2, the audit checks were within 2% of the bottle value over all three routes. Some of the quad blends were low concentrations and the effects of elevation changes were significant enough to prevent meeting the 2% specification in the CFR for CO, CH_4 and THC. THC was within 3% and CO and CH_4 were within 5% for all test routes. If the audit bottles with the lower concentrations are excluded, then the remaining CO and CH_4 audits were within the 2% CFR specification.

Test Date	Audit/cal	Route	THC	CH_4	CO	NO	CO_2
9/22/2006	audit1	1a	47.7	n/a	25.1	148	1.43
9/26/2006	audit2	1b	47.7	n/a	25.1	148	1.43
9/27/2006	audit3	2	47.7	9.27	90.6	100	1.554
9/28/2006	audit4	3	47.7	23.73	229	271.8	3.63
9/22/2006	cal1	1a	89.4	27.83	70.5	278.9	2.604
9/26/2006	cal2	1b	47.9	14.93	37.8	150.1	1.667
9/27/2006	cal3	2	47.9	14.93	37.8	150.1	1.667
9/28/2006	cal4	3	47.9	14.93	37.8	150.1	1.667

Table 5-1. MEL audit and calibration ranges for on road tests audits.

The gaseous instruments are affected by changes in barometric pressure. CE-CERT found that NO_x was not affected by barometer changes but CO_2, CO, THC and CH_4 were affected by the change in barometric pressure. The CO_2 and CO instruments used had a reference cell that was open to the atmosphere and corrected for most of the deviations but needed some additional corrections. THC and CH_4 zero and span were affected by changes in pressure. The pressure effect on FID zero and span made it hard to correct the FID data at the low concentration levels measured during the correlation. The FID zero changed 2-3 ppm and the span changed 6 ppm with a difference in 6000 feet of elevation. Based on the low levels measured during the correlation and the ability to make barometer corrections, the THC and CH_4 data may have had larger deviations than is expected in the CFR.

The ambient background levels for each emissions component were measured along the test route. These results are summarized in Table 5-2. Ambient levels are relatively low for NO_x and

CO_2 compared to exhaust levels for these emissions. THC and CO ambient levels, on the other hand, were comparable to their exhaust sample levels for the DPF equipped vehicle.

Date	Test Run		THC ppm C1	CH_4 ppm C1	CO ppm	NO_x ppm	CO_2 %
9/22/06	San Diego, CA (round trip)	Ave.	2.26	2.27	0.83	0.24	0.04
		Stdev.	0.09	0.16	0.34	0.11	0.00
9/27/06	Riverside, CA to Bishop, CA	Ave.	2.19	1.91	0.46	0.12	0.04
		Stdev.	0.09	0.13	0.17	0.08	0.00
9/28/06	Bishop, CA to Riverside, CA	Ave.	2.12	1.97	0.99	0.07	0.03
		Stdev.	0.08	0.12	0.31	0.05	0.00

Table 5-2. Ambient Background Levels Over Different Test Routes

5.2 Calculation Methods

The NTE data are calculated using three different methodologies to obtain brake specific emission factors for NO_x, NMHC, CO, and CO_2. The calculations for each of the three methods are presented in Appendix D and are briefly summarized below. The calculations use slightly different methodologies to determine the emissions factors. The first method utilizes the straight speed and torque to determine the brake specific emission factors. The second method uses the brake specific fuel consumption to determine the brake specific emission factors. The third method uses the mass fuel flow or a fuel specific method to determine the brake specific emission factors. It should be noted that while these calculations provide a generalized perspective of the different calculations, there are important differences in how these calculations are applied and the order in which different values are summed that are more readily apparent in the full calculations in Appendix D.

$$\boxed{Method\,1 = \frac{\sum g}{\sum Work}}$$

$$\boxed{Method\,2 = \frac{\sum g}{\sum \left[\frac{CO_2\ fuel}{ECM\ fuel} \times Work \right]}}$$

$$\boxed{Method\,3 = \frac{\sum \left[g \times \frac{ECM\ fuel}{CO_2\ fuel} \right]}{\sum Work}}$$

The data from the test runs was compiled by CE-CERT for both the MEL and the PEMS. All calculations for the MEL data were performed by the CE-CERT. The data files for the PEMS were subsequently time aligned and corrected for drift by the PEMS manufacturer. The time alignment was performed using the standard post processing feature in the PEMS software. The drift correction was performed using a beta software version that is not yet commercially available.

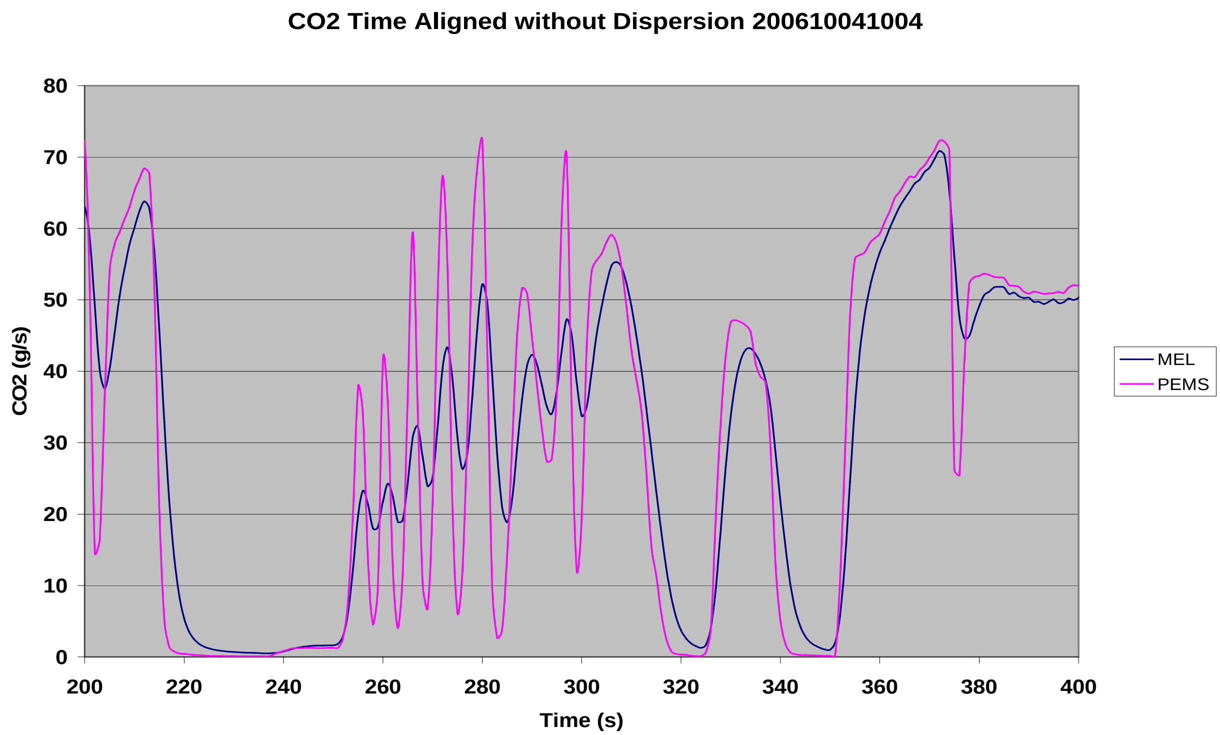
In comparing the humidity correction factors for the MEL and PEM, differences ranging from 0-2.5% were found over the course of the testing. After reviewing the ambient data and corresponding humidity correction factors, it was speculated that absence of the weather shield may have impacted the ambient measurements made by the PEMS. This, in turn, could adversely affect the biases between the PEMS and MEL. It was decided by the steering committee that for the final data set, the humidity correction factors for the MEL system would be used for both the MEL and PEMS to eliminate this source of error. As such, the resulting comparisons do not account for any errors that might be associated with the humidity correction factors determinations between the different systems.

For the PEMS, the drift correct values were compared against the uncorrected values by the PEMS manufacturer to determine the validity of the test for each NTE event. In accordance with §1065.672 [Federal Register / Vol. 70, No. 133 / Wednesday, July 13, 2005], The drift limit between the corrected and uncorrected values can not excel 4% of the NO_x NTE threshold or 4% of point if the BS NTE values is greater than the NTE threshold (here 2 g/hp-hr). The 4% threshold also applies for CO emissions, while the threshold for THC is slightly higher at 10%. The current beta version of the PEMS software makes all comparisons based on % of point, which is consistent with the 1065 requirements for NO_x, since all measured NO_x emissions values were above the NO_x NTE threshold. Based on these comparison checks, 16 events were found to fail for the PEMS based on the drift limit. Additionally, all the test values for the day one round trip to San Diego (in-cab) were excluded since the drift correction comparison could not properly be performed. For CO and NMHC, the measured values were all considerably below the NTE thresholds, hence not tests were invalidated based on the drift limit for these species. For the MEL system zero and span checks were performed hourly, hence the results over the course of the day were considered drift correct. A separate attempt was not made to generate an "undrift corrected" data set for the MEL for comparison. Separate comparisons were made of the system drift over the data, however, as discussed below, and the drift was found to be much less than the 1065 drift limits that would invalidate any test runs.

One additional set of calculations was also performed using a dispersion model to account for the differences in the time constants for the analyzer responses. Specifically, the configuration for the MEL sampling system and associated dilution tunnel has a longer time constant for CO_2 than that for the PEMS, and as such shows some peak broadening that can impact the analyzer comparisons. This effect is shown in Figure 5-1(a), which shows a second by trace of CO_2 emissions for the MEL vs. the PEMS for one test file. While the MEL peaks are broader than those of the PEMS, they are still well within the limits specified in 1065, with a rise time from the 10% to 90% level of 2.7 seconds for CO_2 compared to the maximum allowable time of 5 seconds. The time constant for NO_x is less than that for CO_2, hence the results are less impacted by the dispersion. While the impact of dispersion on the analyzer comparisons is relatively minor for the method 1 calculations, this impact can be greater for methods 2 and 3 since these calculation methods require the calculations of ratios of either the ECM mass fuel rate or BSFC to the CO_2 mass emission rate on a second by second basis.

For the data calculations with dispersion, EPA utilized a dispersion model based on analyzer broadening to disperse the PEMS data such that dispersion differences between the PEMS and MEL were minimized or nearly eliminated. This model was based on a previous investigation of analyzer dispersion by Ganesan and Clark (2001). A comparison of the data after dispersion is provided in Figure 5-1(b) CE-CERT also examined a subset of NTE events using a separate but similar dispersion model and found the impacts on the percentage differences to be similar to those from the EPA (Truex et al., 2000).

One additional item on the calculations is worth noting. Methods 2 and 3, as shown in Appendix D, utilize the brake specific fuel consumption (BSFC) and fuel mass flow, respectively, in the calculations for determinations related to fuel usage. For the present testing, BSFC values were not available over the entire range needed for the calculations. As such, BSFC was determined using a combination of the mass fuel flow and work for method 2 instead of BSFC. This would lead to a closer agreement between the method 2 and 3 calculations than would likely be found if the actual BSFC values were available.



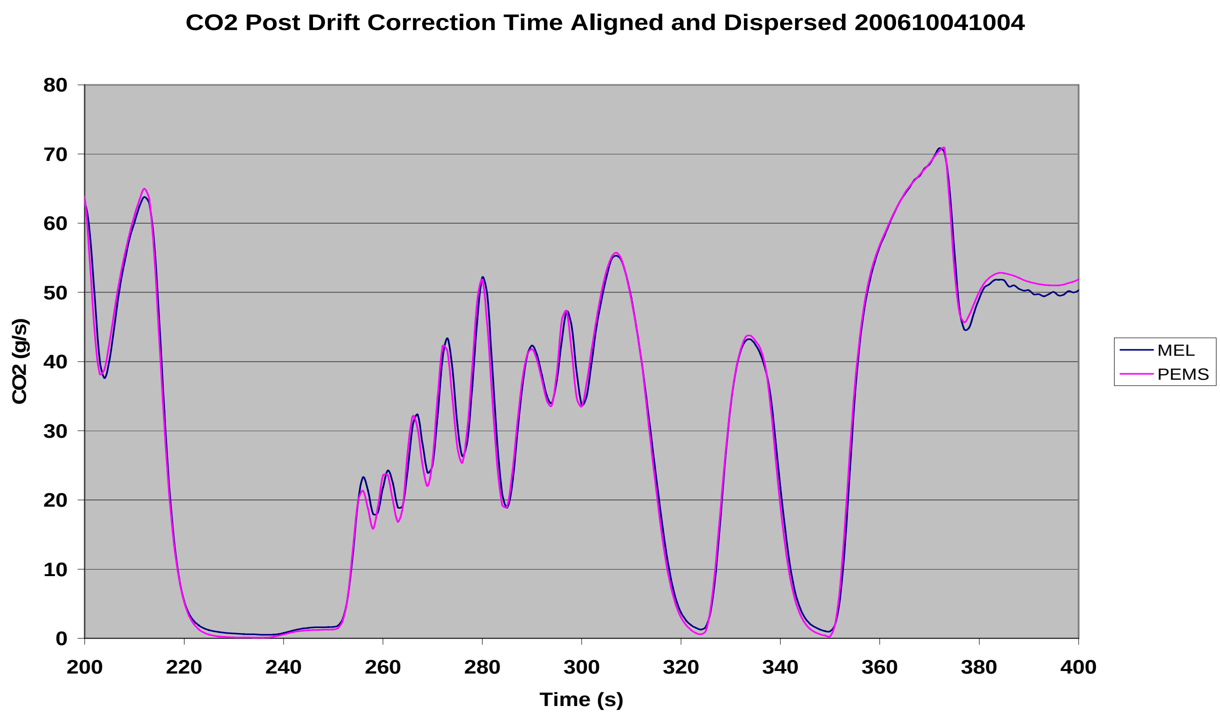


Figure 5-1. Comparison of Real-Time CO_2 Emissions (a) Before Dispersion is Compensated for and (b) After Dispersion is Compensated for.

5.3 Summary of NTE Events

A total of 6 comparisons runs were conducted with the PEMS in either the in cab or out of cab position. The number of NTE events identified in total and for the individual MEL and PEMS units are summarized in Table 5-3. Total number of identified NTE events varied for different test days between 48 and 87. Over the course of the daily test runs, the number of mismatched events (i.e., events identified by either the MEL or PEMS but not both) varied from 3 to 7.

Date	Test Run	PEMS Position	Total NTE	CE-CERT NTE	PEMS NTE	Mismatched Events
10/3/06	San Diego, CA (round trip)	in cab	70	69	65	6
10/4/06	Riverside, CA to Bishop, CA	in cab	87	85	82	7
10/5/06	Bishop, CA to Riverside, CA	in cab	71	68	70	4
10/10/06	San Diego, CA (round trip)	out of cab	48	47	46	3
10/11/06	Riverside, CA to Bishop, CA	out of cab	83	83	80	3
10/12/06	Bishop, CA to Riverside, CA	out of cab	67	66	64	4

Table 5-3. Summary of NTE Events for Each Test Day

Over all six days of sampling, a total of 426 NTE events were identified by either the MEL, the PEMS or both. Of these events, there were a number of NTE events that had differences in start time or event duration as well as events that were not identified by both the MEL and PEMS.

Figures 5-2 and 5-3 show typical examples of mismatched NTE events. In Figure 5-2 both the MEL and PEMs starting at the same time, but the PEMs ended after 60 seconds and the MEL continued. For this event the MEL had one NTE and the PEMs had two NTE's. On a different test, as shown in Figure 5-3, the MEL ended and PEMs continued. One reason for early dropout could be attributed to averaging differences. The ECM broadcast J1939 torque and rpm data rate is typically 10 Hz, but could fluctuate from 5 to 10 Hz on the vehicle network. If the PEMs samples the first five records and the MEL samples the last five records of a 10 record per second data set, then different averages will be calculated by each system. The difference in these calculated averages could cause one system to dropout while the other remains in the event. The calculated averaged differences will be largest on rapid torque transitions. Notice in Figures 5-2 and 5-3 that the dropout by one of the two systems occurred during a rapid torque condition.

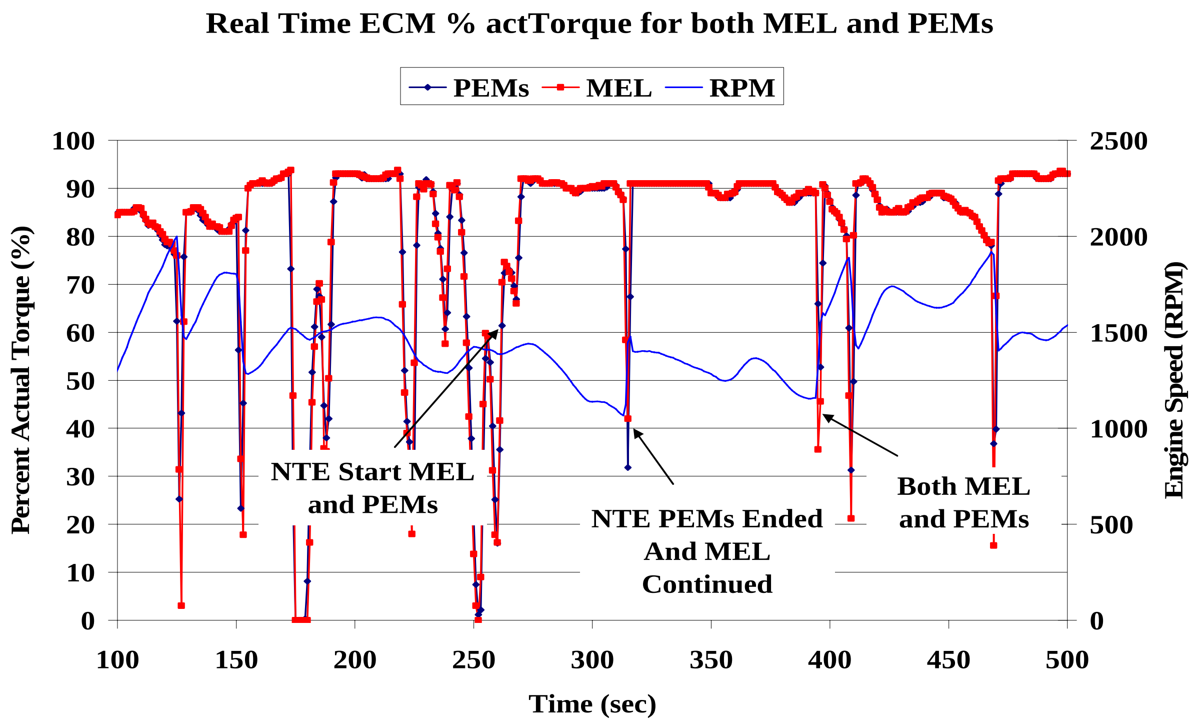


Figure 5-2. Real-time ECM % actTorque for both MEL and PEMS.

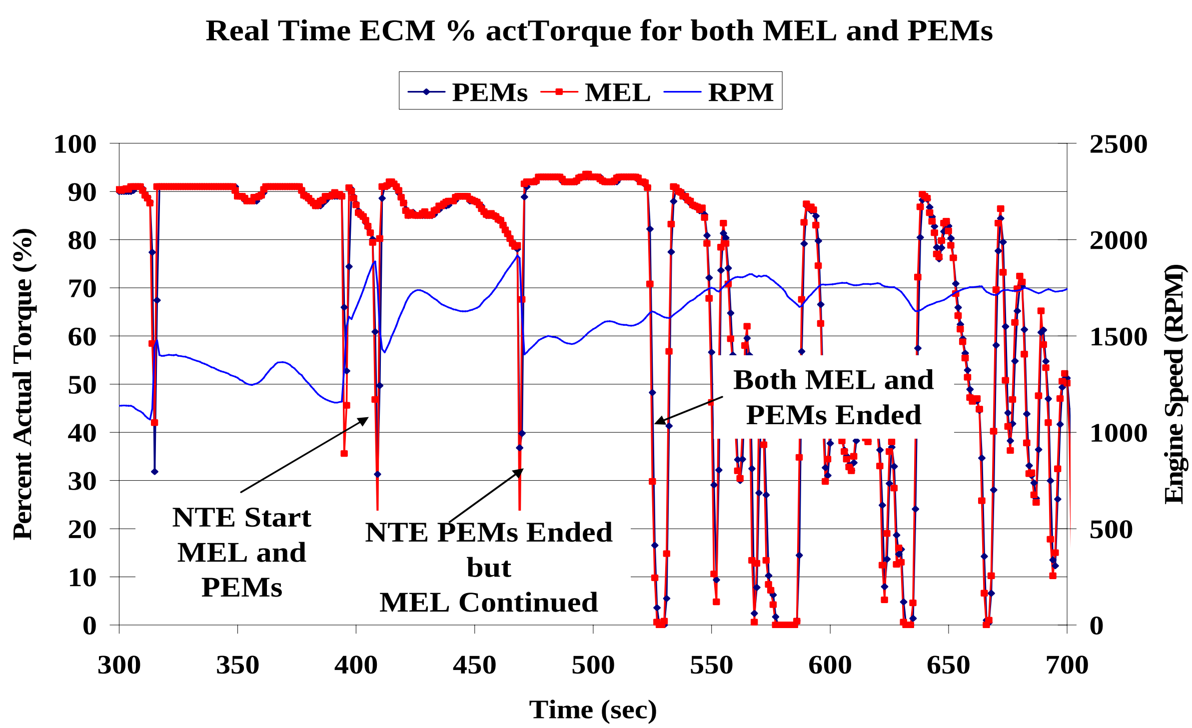


Figure 5-3. Real-time ECM % actTorque for both MEL and PEMS.

In order to compare identical events, NTE events that have common start and duration times must be matched. For the remaining analyses in this section, the analyses were limited to those NTE events where the start time for the NTE event matched to within 3 seconds or less and the event duration matched to within 1 second or less between the MEL and the PEMS. This represented a total of 343 events. This essentially eliminates the errors associated with NTE events of different start times or durations and allows a straight comparison in the emissions differences between the MEL and PEMS. NTE events where the data did not pass the drift limit validity check, as discussion in the previous section, were also excluded. This included all the data from the first test day since the post-test zero span data were not available. All of the remaining Figures in this section are based on only this subset of NTE events.

5.4 Full Route Statistics and Emissions Results

It is useful to evaluate the cycle statistics to better understand the NTE driving conditions in the context of the larger scope of on-road driving conditions. It is important to note the routes for the on-road validation were structured to emphasize data collection within the NTE zone of engine operation. That is, while the overall driving routes included some stop-and-go vehicle/engine operation, data were generally recorded only during higher speed, quasi-steady-state engine operation, and hence very little data collection occurred during vehicle/engine operation under stop-and-go driving conditions. The combined average speed for all 32 runs (almost 27 hours of data collection) was about 50 mph. The NTE is structured to emphasize compliance during quasi-steady-state highway-cruise-type operation, and hence the data collection targeted this type of engine operation. Appendix E provides vehicle speed and engine and torque versus time traces for a subset of test runs and Appendix F provides a summary table of average vehicle and engine speeds and torques for the individual routes and overall route summary.

A summary of the trip statistics is provided in Table 5-4, including total time, miles driven, and % of VMT in an NTE event. These statistics are all generated based on data collected with the CE-CERT MEL. These data show that approximately 20-32% of the route time was spent in an NTE event. Similarly, 21-34% of the mileage on the trip was in an NTE event. Similar data are presented graphically in Figure 5-4. Figure 5-4 also shows the percentage of time and mileage spent in the NTE zone as a whole. The data within the NTE zone represents a larger fraction of the data since the NTE zone characteristics must be satisfied for a continuous period of 30 seconds in order to be classified as an NTE event. The data show that on average approximately 50-56% of the time, 53-63% of the mileage, and 76-78% of the trip power was found to be under conditions in the NTE zone (see Table 1-1), although not all of this time was also under a continuous 30 second interval required for an NTE event. The data do show a trend of higher percentages of time and distance in the NTE zone on the uphill route to Bishop vs. more downhill return trip from Bishop to Riverside, which is not unexpected since higher power on average would be needed for an uphill climb. Note that the cycles were specifically designed to provide a greater emphasis on NTE events, so the % of travel in the NTE zone for these routes is probably higher than what would typically be seem in normal driving. In heavy congestion, for example, it is expected that very few actual NTE events would occur.

Date	Test Run	PEMS Position	Time NTE	Total Route time	% trip time in NTE zone	VMT NTE	Total Trip VMT	% trip VMT in NTE zone
10/3/2006	San Diego, CA (round trip)	in cab	3387	12000	28.2%	44.1	150.8	29.2%
10/4/2006	Riverside, CA to Bishop, CA	in cab	5604	18000	31.1%	79.0	229.6	34.4%
10/5/2006	Bishop, CA to Riverside, CA	in cab	4995	18000	27.8%	71.9	232.6	30.9%
10/10/2006	San Diego, CA (round trip)	out of cab	2925	12000	24.4%	39.8	154.6	25.8%
10/11/2006	Riverside, CA to Bishop, CA	out of cab	5767	18000	32.0%	81.9	225.2	36.4%
10/12/2006	Bishop, CA to Riverside, CA	out of cab	3619	18000	20.1%	50.6	236.0	21.4%
	All Cycles		26297	96000	27.4%	367.3	1228.8	29.9%

Table 5-4. Summary of Travel Statistics for the On-the-Road Routes

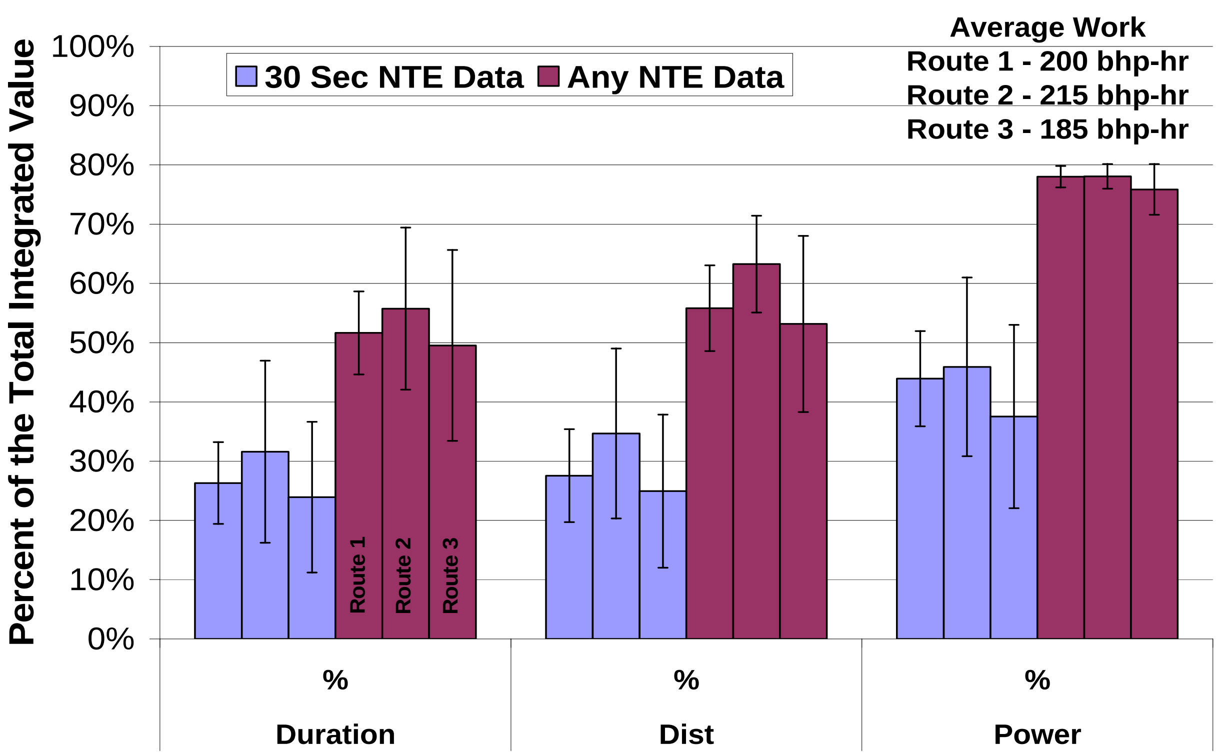


Figure 5-4. Real-time ECM % actTorque for both MEL and PEMS.

A comparison of emission results over the entire driving route vs. the emissions within an NTE event is provided in Table 5-5. The results indicate that emissions on a g/kW-hr basis were fairly comparable between an NTE event and over the entire route. On a per mile basis, however, the emissions within an NTE event were higher than those found over the entire cycle. This is not surprising since on average, it is expected that higher power events would be expected within an NTE event compared to the full range of driving conditions. This is consistent with the results in Figure 5-4, which show a greater percentage of power for the NTE event region in comparison with either the time or mileage spent within an NTE event. It is interesting that the ratios of NO_x within an NTE event to NO_x over the entire route and CO_2 within an NTE event to CO_2 over the entire route are very similar for nearly all routes, and vary within a range of 1.5 to 1.9. This indicates that the higher NO_x levels on a per mile basis within an NTE event can likely be attributed to higher power events/greater fuel consumption.

Date	Test Run			NO_x	CO	NMHC	CO_2
10/3/2006	San Diego, CA (round trip)	g/kW-hr	In NTE	3.3	0.026	0.003	656
			Entire route	2.9	0.033	0.003	589
		g/mi	In NTE	21.0	0.163	0.018	4117
			Entire route	11.7	0.129	0.013	2342
10/4/2006	Riverside, CA to Bishop, CA	g/kW-hr	In NTE	3.8	0.017	0.005	684
			Entire route	3.6	0.023	0.007	609
		g/mi	In NTE	21.7	0.095	0.030	3948
			Entire route	14.8	0.095	0.031	2538
10/5/2006	Bishop, CA to Riverside, CA	g/kW-hr	In NTE	3.6	0.017	0.003	682
			Entire route	3.4	0.022	0.003	601
		g/mi	In NTE	20.4	0.093	0.015	3823
			Entire route	13.4	0.085	0.014	2355
10/10/2006	San Diego, CA (round trip)	g/kW-hr	In NTE	3.5	0.026	0.001	651
			Entire route	3.1	0.026	-0.001	584
		g/mi	In NTE	21.8	0.160	0.006	4078
			Entire route	11.9	0.100	-0.002	2262
10/11/2006	Riverside, CA to Bishop, CA	g/kW-hr	In NTE	3.6	0.014	0.003	694
			Entire route	3.4	0.013	0.003	618
		g/mi	In NTE	22.2	0.088	0.019	4233
			Entire route	14.8	0.056	0.015	2713
10/12/2006	Bishop, CA to Riverside, CA	g/kW-hr	In NTE	3.5	0.016	0.003	695
			Entire route	3.5	0.026	0.003	624
		g/mi	In NTE	19.4	0.088	0.014	3831
			Entire route	11.1	0.084	0.010	2004
	All Cycles	g/kW-hr	In NTE	3.6	0.018	0.003	680
			Entire route	3.3	0.023	0.004	606
		g/mi	In NTE	21.2	0.107	0.018	4009
			Entire route	13.1	0.089	0.014	2374

Table 5-5. MEL Emissions for Entire Route and in the NTE Zone.

5.5 NO_x NTE Emission Results

Correlation plots for NO_x emissions between the MEL and PEMS are provided for the common NTE events for brake specific emissions in Figure 5-5 and for total grams in Figure 5-6. The brake specific emissions are shown for each of the calculation methods. An event by event comparison of NTE events for brake specific NO_x emissions for the MEL and PEMS is provided in Appendix G. This appendix also indicates the points that were eliminated due to failed drift correction. The results show the PEMS measurements are generally biased high relative to the MEL, with the largest bias seen for the method 1 calculations.

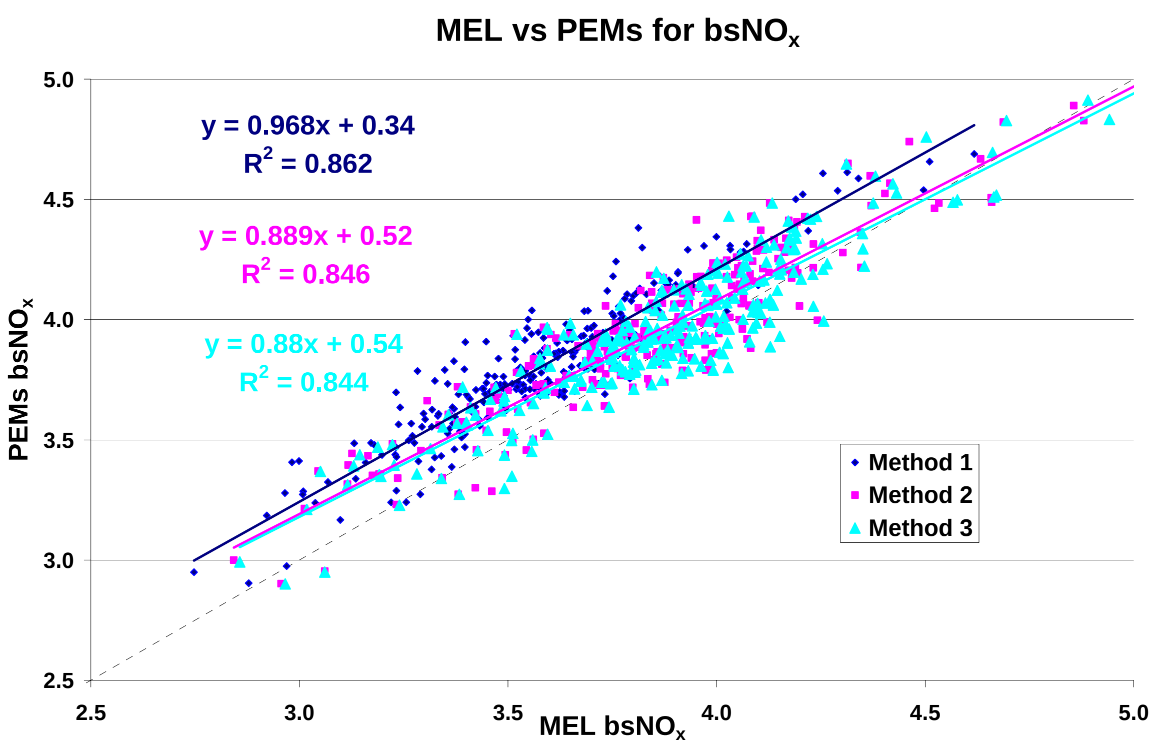


Figure 5-5. NO_x Mass Emissions (g/bkW-hr) for PEMS Relative to MEL

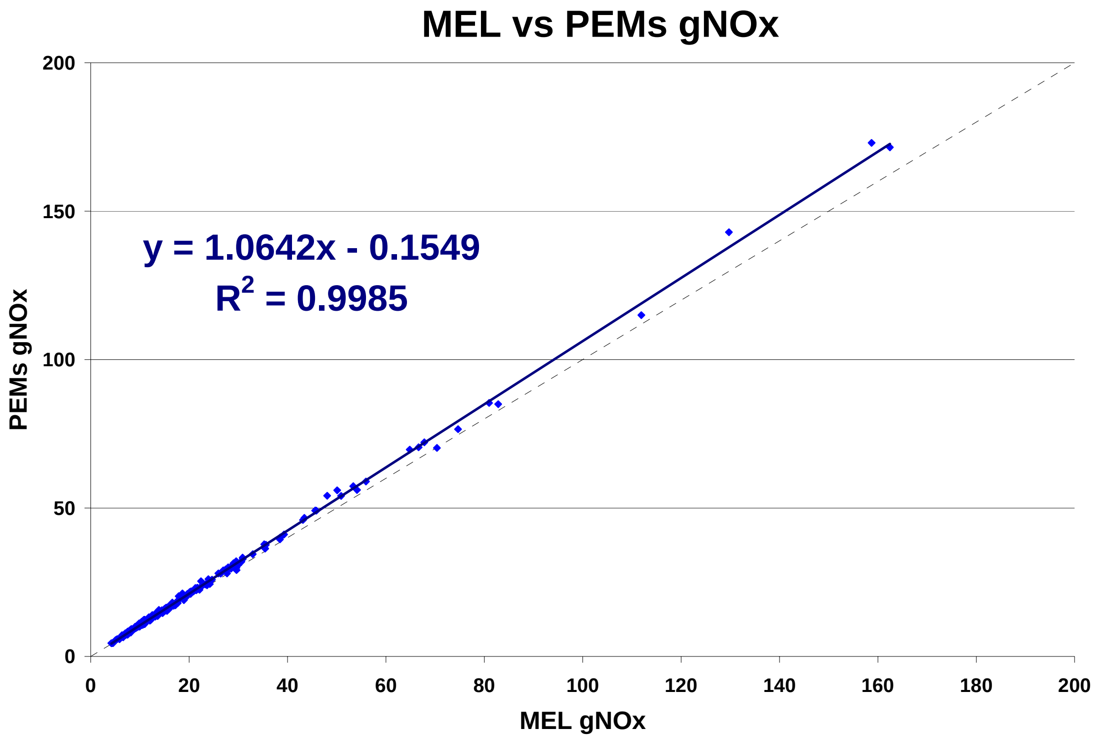


Figure 5-6. NO_x Mass Emissions (g) for PEMS Relative to MEL

The deviations in the brake specific emissions relative to the NTE NO_x standard (2.0 grams per brake horsepower-hour or 2.68 grams per brake kW-hour) are provided in Figure 5-7 on an event by event basis. The absolute deviations as a function of the total NO_x emissions as measured by the MEL are provided in Figure 5-8. The results are summarized in Table 5-6 on a relative basis to the NTE standard and for the absolute differences. The deviations are shown for the 3 different calculation methodologies. The deviations were greatest for the method one calculation, with an average deviation of +8%±4% of the NTE standard over all points, where the error represents one standard deviation. The deviations for methods 2 and 3 were +4%±5% and +3%±5%, respectively, over all points. The differences in the deviations for the different calculation methods could be related to the incorporation of CO_2 exhaust measurements into calculations 2 and 3. As the CO_2 is also biased high, as shown in the next subsection, this should have the effect of normalizing the emissions differences. Methods 2 and 3 are also somewhat impacted by analyzer dispersion, as will be discussed further below. The deviations relative to the proposed NTE NO_x standard (2.68 grams per brake kW-hour) are slightly higher than those on a relative basis, since the emissions measurements were generally above the NTE standard. On a relative basis, the deviations were +6%±3%, +3%±4%, and +2%±4%, respectively, for calculation method 1, 2 and 3. The results for the relative percent deviations of point are provided in Figure 5-9 and in Table 5-7.

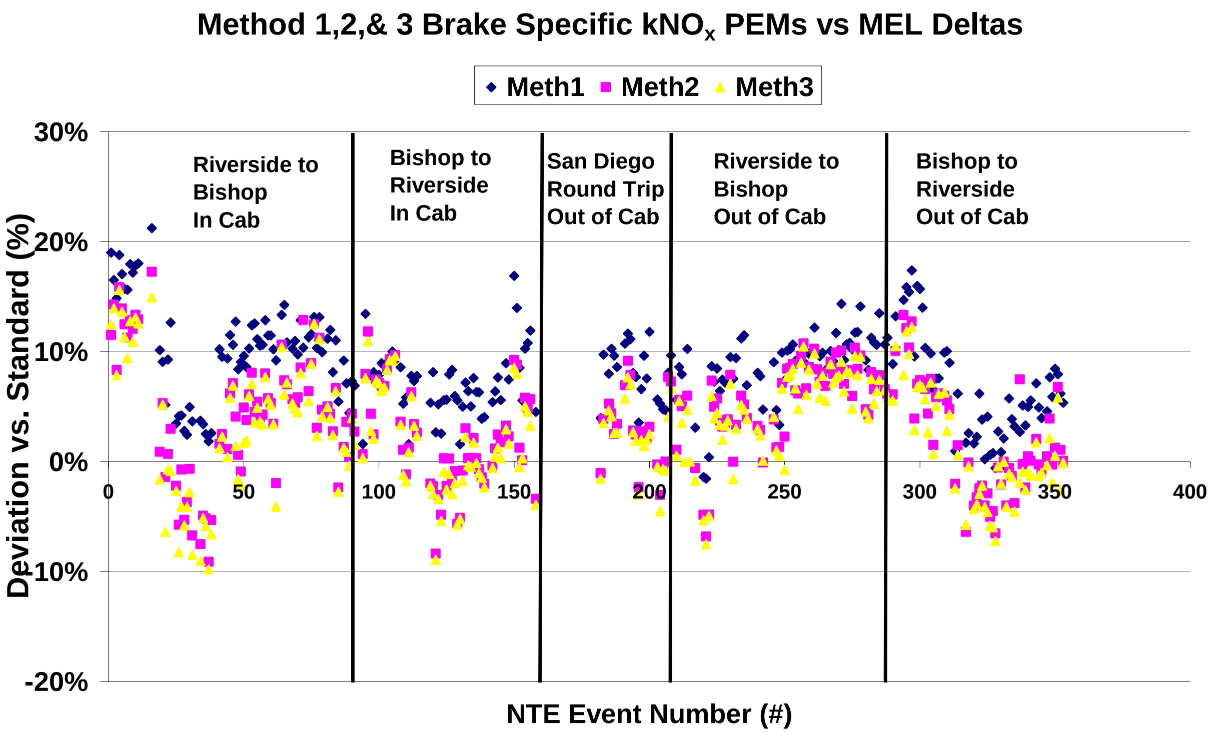


Figure 5-7. Deviations in % Relative to the Standard for NO_x on an NTE Event Basis

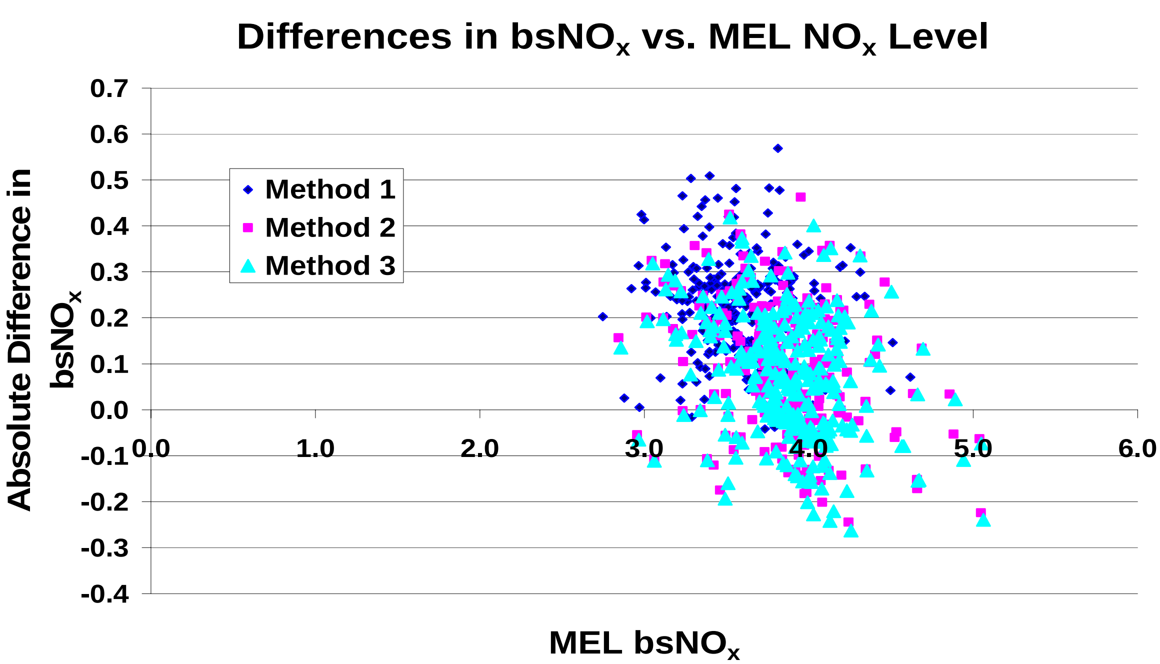


Figure 5-8. Absolute Differences for NO_x (g/bkW-hr) Compared to NO_x Emission Level (g/bkW-hr)

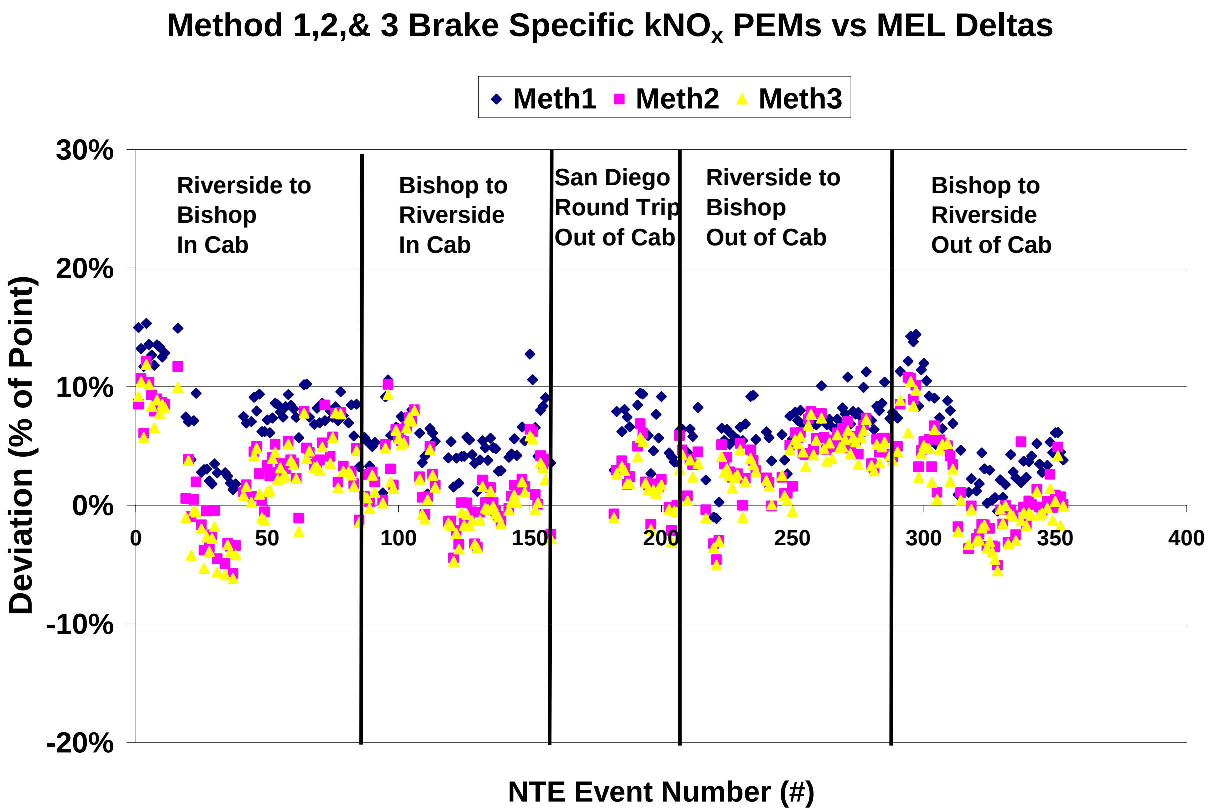


Figure 5-9. Deviations in % of Point for NO_x on an NTE Event Basis

There were some differences for the deviations between the different test runs or segments/days, which could be due to a variety of factors such as environmental conditions, altitude, and analyzer drift. These data were not analyzed in detailed, although there is some indications that zero drift for the PEMS may have contributed to variability within the testing. In general, comparisons between test days or routes indicate most of the conditions were comparable within the experimental variability. A two-tailed, paired t-test between the MEL and PEMS NO_x results for individual NTE events, as provided in Table 5-6, showed that the differences in emissions between the MEL and PEMS were highly statistically significant for nearly all test conditions. The only comparisons that were not statistically significant for at least the 95% confidence level were the method 3 calculations for the out of cab Bishop, CA to Riverside, CA run.

Test day/points	Trip	PEMS Position	Method	Average Difference vs. Standard	St Dev	Absolute Difference (g/kW-hr)	t-test
All points			1	8%	4%	0.22	4.97E-99
			2	4%	5%	0.10	3.56E-26
			3	3%	5%	0.07	5.67E-17
10/4/2006	Riverside, CA to Bishop, CA	in cab	1	11%	5%	0.28	7.90E-30
			2	5%	6%	0.12	3.237E-08
			3	4%	6%	0.09	2.59E-05
10/5/2006	Bishop, CA to Riverside, CA	in cab	1	7%	3%	0.19	2.23E-26
			2	2%	4%	0.06	2.80E-04
			3	2%	4%	0.04	9.25E-03
10/10/2006	San Diego, CA (round trip)	out of cab	1	8%	3%	0.21	3.51E-11
			2	3%	3%	0.07	0.00194
			3	2%	3%	0.05	0.0118
10/11/2006	Riverside, CA to Bishop, CA	out of cab	1	9%	3%	0.24	8.21E-33
			2	6%	4%	0.15	1.56E-18
			3	5%	4%	0.13	7.28E-16
10/12/2006	Bishop, CA to Riverside, CA	out of cab	1	6%	5%	0.17	4.89E-14
			2	2%	5%	0.05	0.00701
			3	1%	5%	0.03	0.135

Table 5-6. Summary of Deviations in % vs. Standard for NO_x Emissions

Test day/points	Trip	PEMS Position	Method	Average % Difference vs. Point	St Dev
All points			1	6%	3%
			2	3%	4%
			3	2%	4%
10/4/2006	Riverside, CA to Bishop, CA	in cab	1	8%	3%
			2	3%	4%
			3	2%	4%
10/5/2006	Bishop, CA to Riverside, CA	in cab	1	5%	2%
			2	2%	3%
			3	1%	3%
10/10/2006	San Diego, CA (round trip)	out of cab	1	6%	2%
			2	2%	2%
			3	1%	2%
10/11/2006	Riverside, CA to Bishop, CA	out of cab	1	7%	2%
			2	4%	3%
			3	3%	3%
10/12/2006	Bishop, CA to Riverside, CA	out of cab	1	5%	4%
			2	2%	4%
			3	1%	4%

Table 5-7. Summary of Deviations in % vs. Point for NO_x Emissions

The deviations for the data generated from the dispersion model are shown in Figure 5-10 in the brake specific emissions relative to the NTE NO_x standard. The results are summarized in Table 5-8 on a relative basis to the NTE standard and for the absolute differences. The results from the dispersion model were fairly similar to those found for the baseline data set. The deviations for the method one calculation were slightly less than those for the baseline data set, with an average deviation of +7%±5% of the NTE standard over all points. The deviations for methods 2 and 3 over all points were +4%±5% and +4%±6%, respectively, with a slight tendency for higher differences than for the baseline data set.

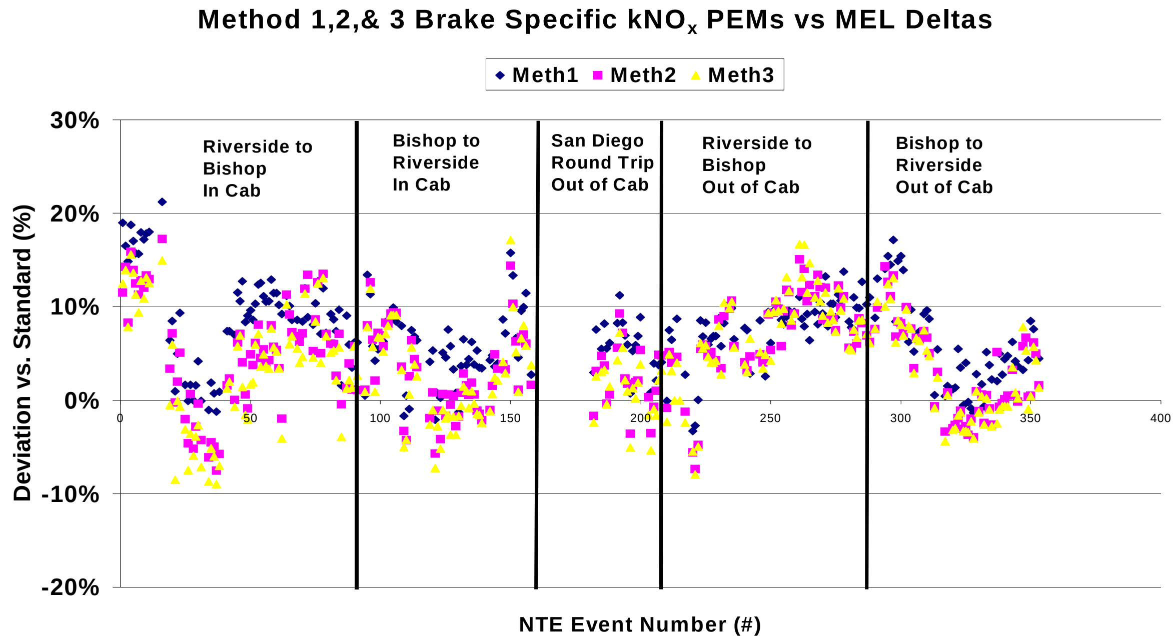


Figure 5-10. Deviations in % Relative to the Standard for NO_x on an NTE Event Basis for Dispersion Data

Test day/points	Trip	PEMS Position	Method	Average Difference vs. Standard	St Dev	Absolute Difference (g/kW-hr)	t-test
All points			1	7%	5%	0.19	7.16E-74
			2	4%	5%	0.12	2.80E-34
			3	4%	6%	0.10	8.72E-24
10/4/2006	Riverside, CA to Bishop, CA	in cab	1	9%	5%	0.25	3.52E-22
			2	5%	6%	0.14	7.90E-10
			3	4%	7%	0.10	1.70E-05
10/5/2006	Bishop, CA to Riverside, CA	in cab	1	6%	4%	0.15	1.32E-16
			2	3%	4%	0.08	2.26E-06
			3	2%	5%	0.06	4.16E-04
10/10/2006	San Diego, CA (round trip)	out of cab	1	6%	3%	0.15	7.37E-08
			2	2%	3%	0.05	0.0128
			3	1%	3%	0.03	0.181
10/11/2006	Riverside, CA to Bishop, CA	out of cab	1	8%	3%	0.21	1.24E-27
			2	7%	4%	0.19	2.32E-19
			3	7%	5%	0.19	1.07E-17
10/12/2006	Bishop, CA to Riverside, CA	out of cab	1	6%	5%	0.17	2.58E-12
			2	3%	5%	0.05	2.73E-05
			3	3%	5%	0.03	2.25E-04

Table 5-8. Summary of Deviations for NO_x Emissions with Dispersion

One other factor that could influence the deviations between the systems is the NO_x converter efficiency. For the MEL, the NO_x converter efficiency for NO_2 to NO was found to be 96.4%. Based on the relative NO_2 values measured in the exhaust by the PEMS, this could result in a 'loss' of 1.8 to 0.8% of NO_x during the MEL measurements, potentially biasing the system low.

5.6 CO_2 NTE Emission Results

The brake specific and total gram CO_2 emissions for the common NTE events are provided in Figure 5-11 and Figure 5-12, respectively. The method 1 results show the PEMS measurements are consistently biased high relative to the CE-CERT MEL, with an $R^2 = 0.97$. The percentage deviations for method 1 CO_2 for the PEMS relative to the MEL value are shown in Figure 5-13. The percentage differences averaged +4%±2%. This is consistent with the correlation plot for grams of CO_2 which shows a slight high bias with an $R^2 = 1.0$. Note that for the method 2 and 3 calculations, the resulting brake specific CO_2 emissions are primarily representative of the values derived from the mass fuel flow from the ECM for both the MEL and PEMS since the measured CO_2 emissions or concentrations largely cancel out of the equation.

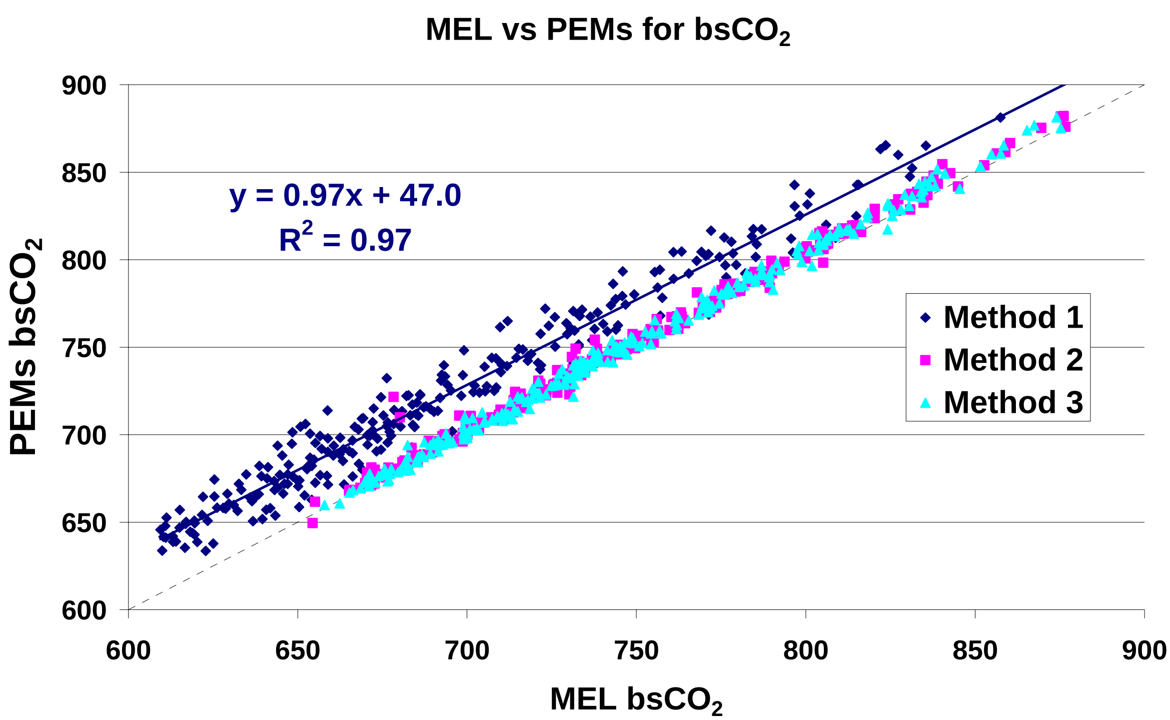


Figure 5-11. CO_2 Mass Emissions (g/bkW-hr) for PEMS Relative to MEL

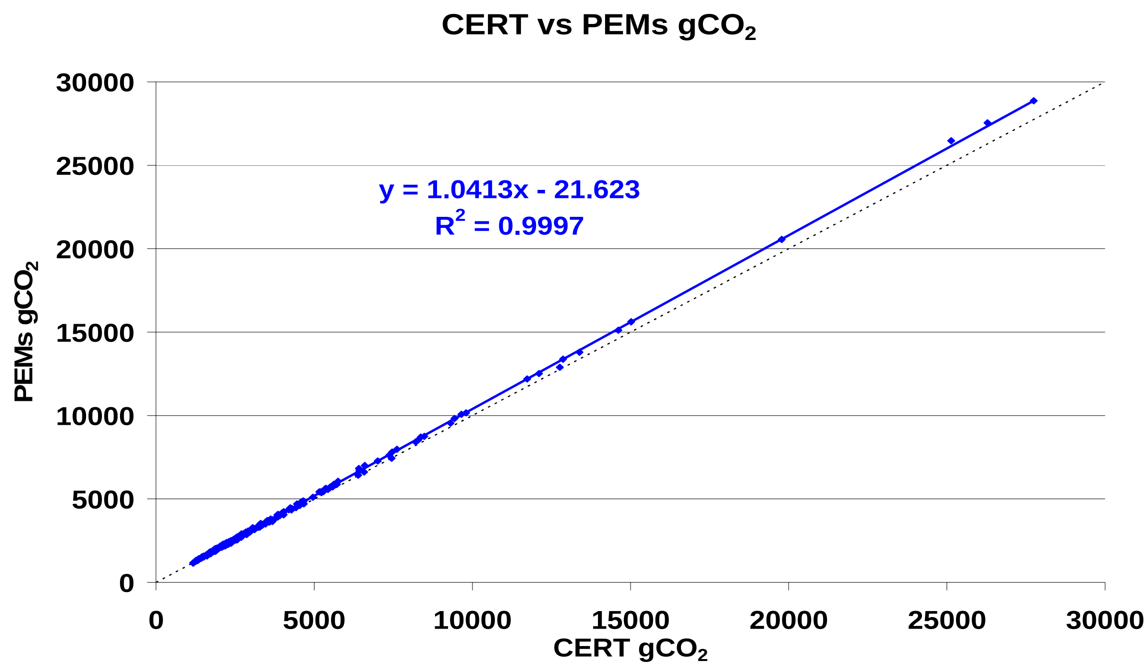


Figure 5-12. CO_2 Mass Emissions (grams) for PEMS Relative to MEL

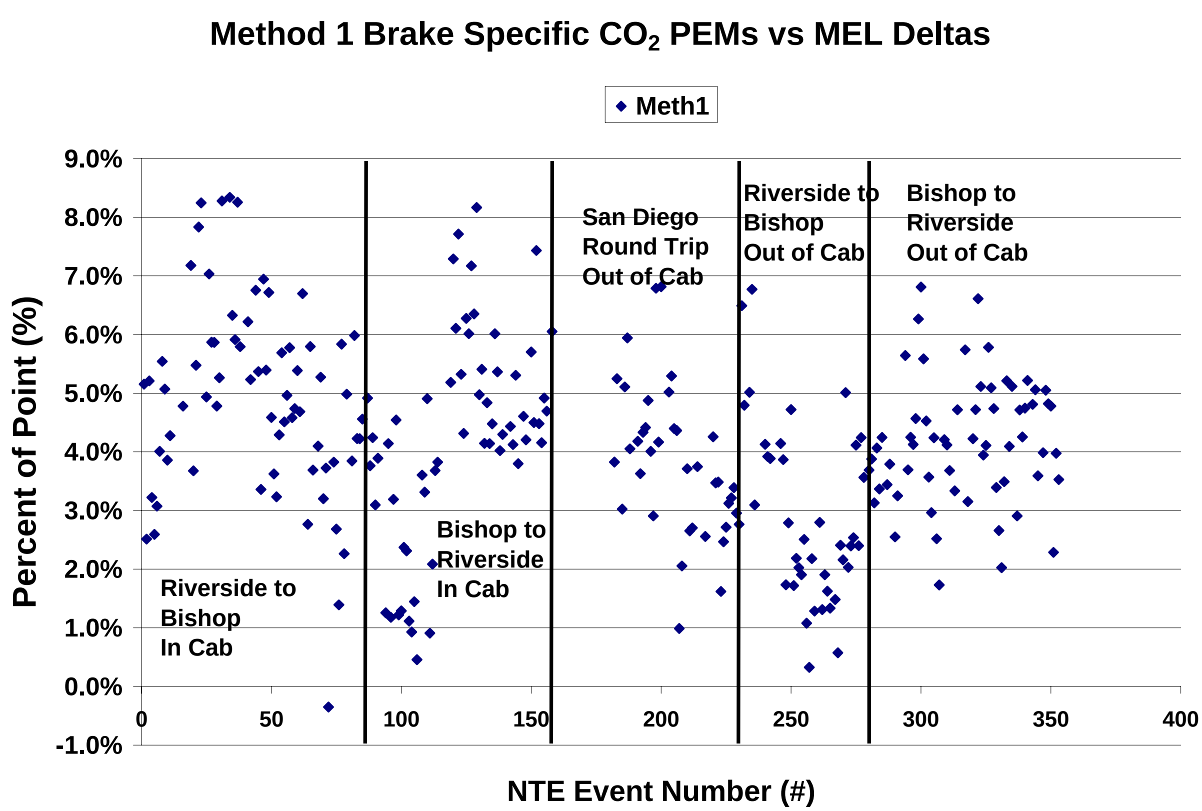
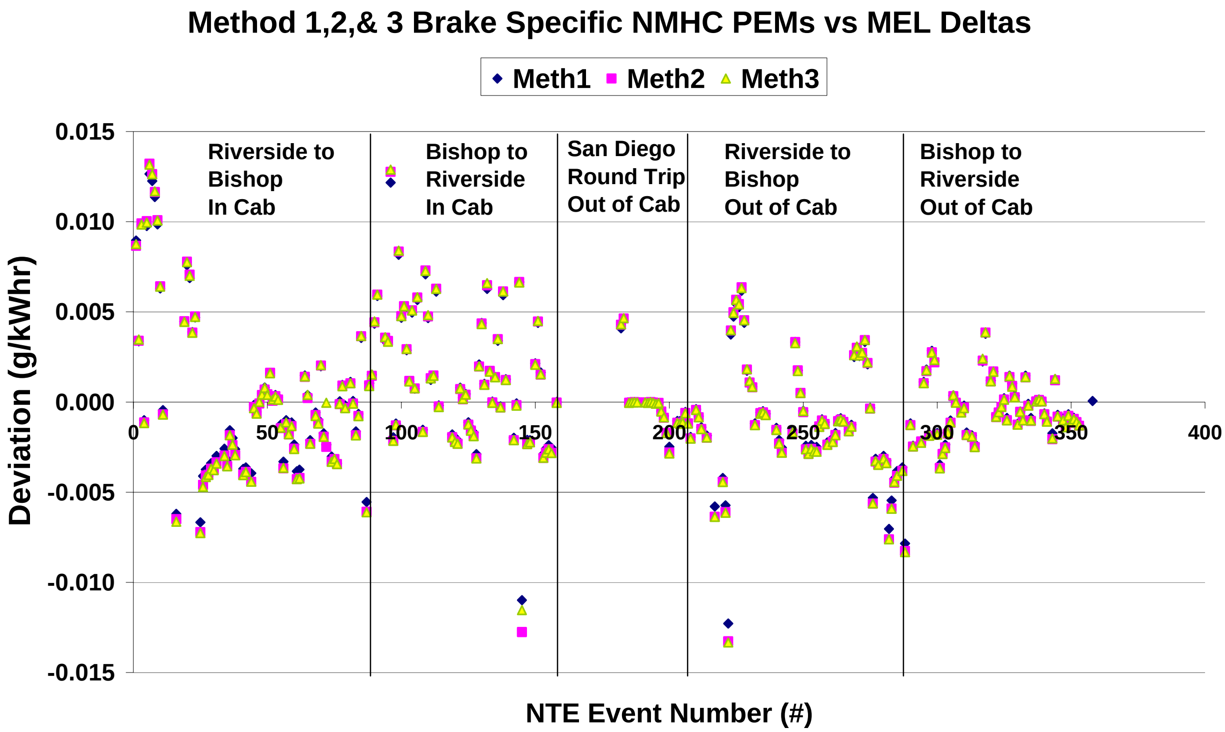


Figure 5-13. CO_2 Mass Emissions (g/bkW-hr) for PEMS Relative to MEL

5.7 NMHC NTE Results

NMHC emissions levels were consistently low for the on-road measurements. The average emission rates for NMHC was 0.003 g/bkW-hr or below, which is around 1% of the anticipated NTE standard of 0.28 g/bkW-hr. For the MEL, the diluted exhaust NMHC concentration levels were comparable to those of the ambient background. The concentration levels are discussed further in section 5.8. The deviations of the NMHC measurements between the PEMS and the MEL are plotted in Figure 5-14 in terms of absolute differences and on a relative basis compared to the NTE standard. There is not consistent bias for NMHC emissions between the different analyzers, with the PEMS higher for some tests and lower for others, albeit at very low levels. Average differences for the different test runs were ±0.5% or less of the NTE standard. The correlation analysis in Figure 5-15 shows relatively weak correlation of R^2 ~0.36/0.37 due to the low level measurements. A summary of the absolute differences and the differences relative to the NTE standard for different test runs is provided in Table 5-9. The t-test comparisons showed that the differences between the analyzers were statistically significant for some test runs but not for others. Over all NTE events, the differences were not found to be statistically significant.



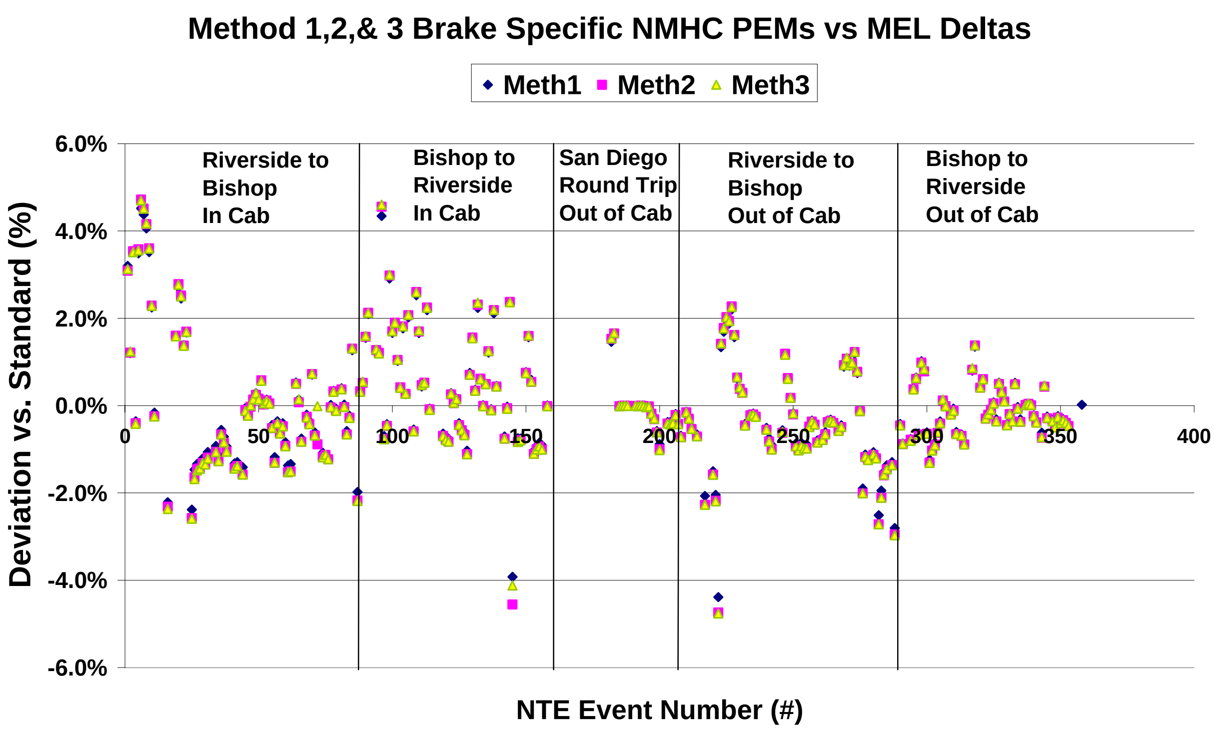


Figure 5-14. Absolute Deviations and Deviations Relative to NTE Standard for NMHC on an NTE Event Basis

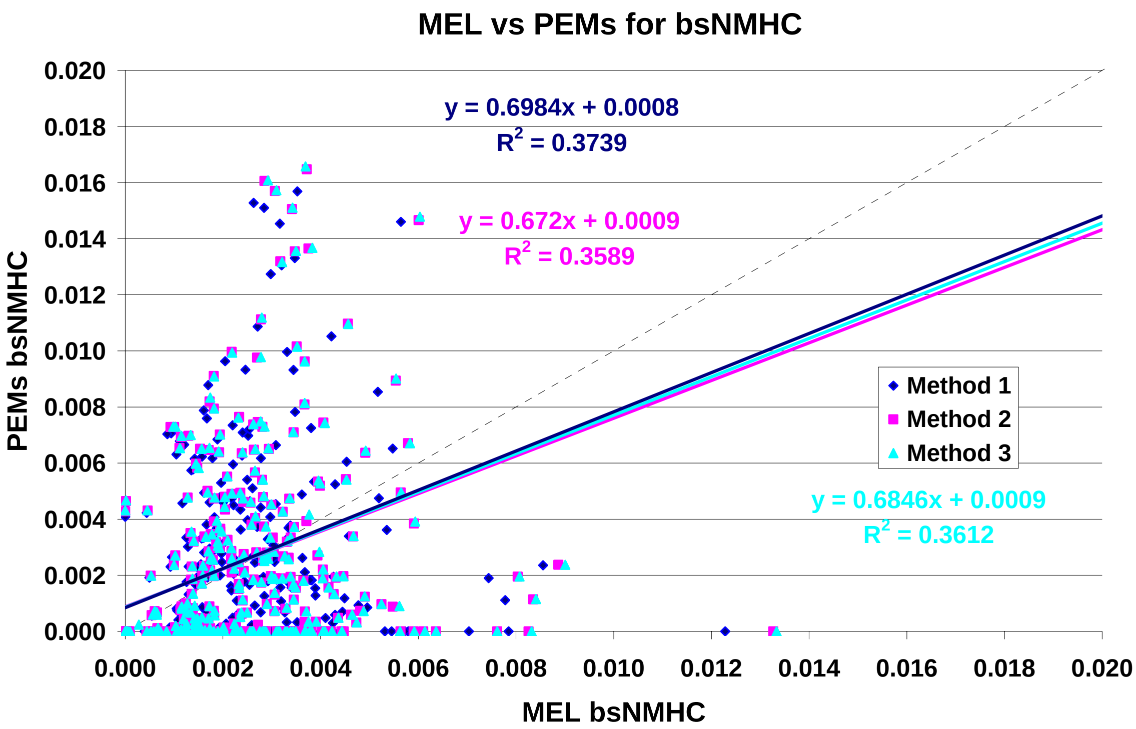


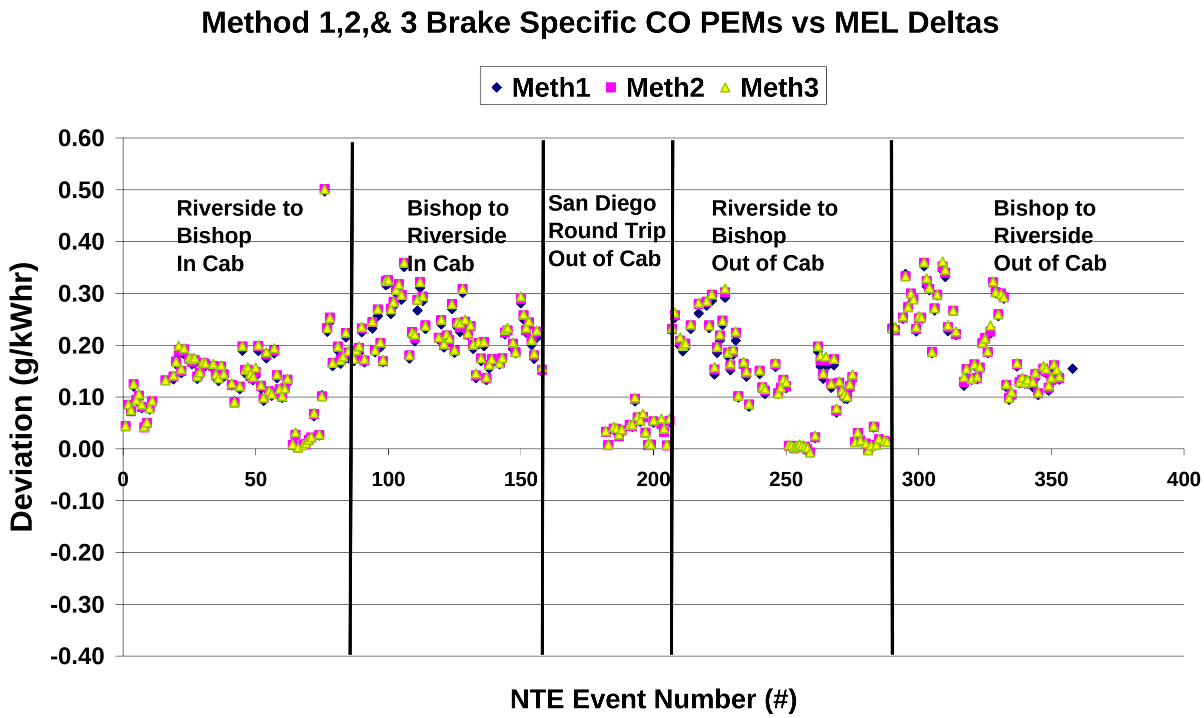
Figure 5-15. NMHC Mass Emissions (g/bkW-hr) for PEMS Relative to MEL

Test day/points	Trip	PEMS Position	Method	Average Difference (g/kW-hr)	St Dev (g/kW-hr)	% Diff vs. Standard	t-test
All points			1	0.000	0.004	0.0%	0.797
			2	0.000	0.004	0.0%	0..861
			3	0.000	0.004	0.0%	0.905
10/4/2006	Riverside, CA to Bishop, CA	in cab	1	0.000	0.005	0.1%	0.556
			2	0.000	0.005	0.1%	0.752
			3	0.000	0.005	0.1%	0.716
10/5/2006	Bishop, CA to Riverside, CA	in cab	1	0.001	0.004	0.5%	0.00449
			2	0.001	0.004	0.5%	0.00963
			3	0.001	0.004	0.5%	0.00762
10/10/2006	San Diego, CA (round trip)	out of cab	1	0.000	0.002	0.0%	0.917
			2	0.000	0.002	0.0%	0.857
			3	0.000	0.002	0.0%	0.850
10/11/2006	Riverside, CA to Bishop, CA	out of cab	1	-0.001	0.003	-0.4%	0.0121
			2	-0.001	0.004	-0.4%	0.00896
			3	-0.001	0.004	-0.4%	0.00891
10/12/2006	Bishop, CA to Riverside, CA	out of cab	1	0.000	0.001	-0.1%	0.0613
			2	0.000	0.002	-0.2%	0.0269
			3	0.000	0.002	-0.2%	0.0308

Table 5-9. Summary of Deviations for NMHC Emissions

5.8 CO NTE Emission Results

For CO emissions, the MEL emissions measurements were very low and the PEMS measurements were consistently higher than those of the MEL. The CO emissions levels were on the order of 0.1% of the anticipated NTE standard of 26.01 g/bkW-hr for CO for the MEL measurements, although the PEMS measurements were higher than this. For the MEL, the diluted exhaust CO concentration levels were comparable to those of the ambient background. The concentration levels are discussed further in section 5.8. The deviations of the CO measurements between the PEMS and the MEL are plotted in Figure 5-16 in terms of absolute differences and on a relative basis compared to the NTE standard. These Figures show that CO emission levels for the PEMS were consistently higher than those for the MEL. The absolute differences represented 1% or less of the NTE standard, although the PEMS measurements were approximately an order of magnitude higher than those for the MEL. The correlation analysis in Figure 5-17 shows again that the PEMS had considerably higher readings than the MEL and that there was essentially no correlation between the measurement methods (R^2 = 0.0011 or less) at these low levels. A summary of the absolute differences and the differences relative to the NTE standard for different test runs is provided in Table 5-10. The t-test comparisons showed that all differences were highly statistically significant.



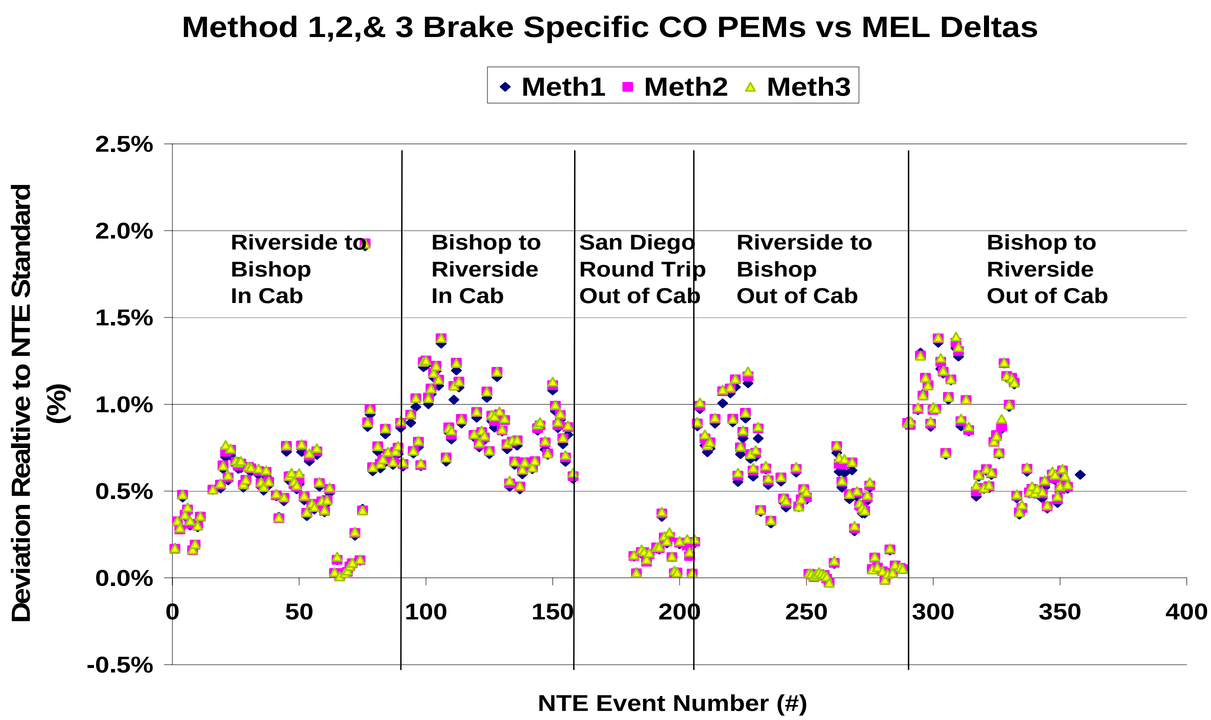


Figure 5-16. Absolute and Relative to NTE Standard Deviations for CO on an NTE Event Basis

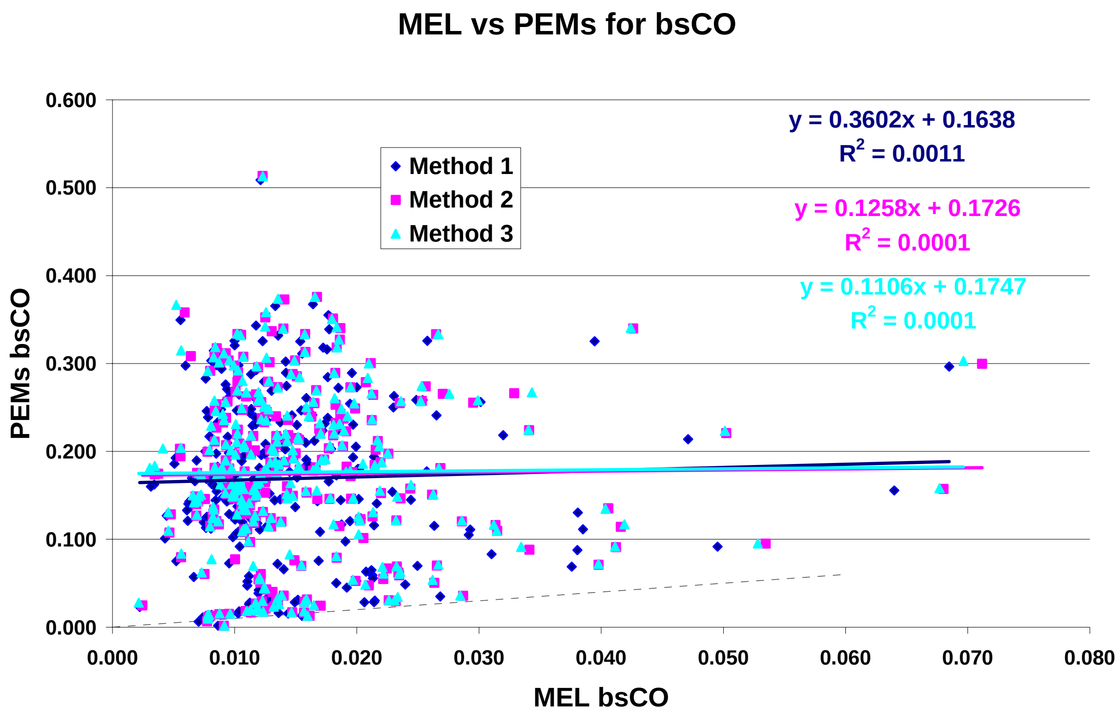


Figure 5-17. CO Mass Emissions (g/bkW-hr) for PEMS Relative to MEL

Test day/points	Trip	PEMS Position	Method	Average Difference (g/kW-hr)	St Dev (g/kW-hr)	% Diff vs. Standard	t-test
All points			1	0.155	0.090	0.6%	1.62E-81
			2	0.159	0.092	0.6%	3.59E-82
			3	0.161	0.092	0.6%	2.98E-83
10/4/2006	Riverside, CA to Bishop, CA	in cab	1	0.126	0.072	0.5%	5.45E-23
			2	0.131	0.074	0.5%	3.97E-23
			3	0.132	0.074	0.5%	2.23E-23
10/5/2006	Bishop, CA to Riverside, CA	in cab	1	0.223	0.050	0.9%	4.99E-40
			2	0.229	0.052	0.9%	5.32E-40
			3	0.231	0.051	0.9%	2.17E-40
10/10/2006	San Diego, CA (round trip)	out of cab	1	0.038	0.021	0.1%	1.41E-07
			2	0.039	0.022	0.1%	2.48E-07
			3	0.042	0.023	0.1%	1.41E-07
10/11/2006	Riverside, CA to Bishop, CA	out of cab	1	0.115	0.087	0.4%	1.03E-15
			2	0.120	0.091	0.5%	1.00E-15
			3	0.122	0.092	0.5%	6.59E-16
10/12/2006	Bishop, CA to Riverside, CA	out of cab	1	0.207	0.078	0.8%	6.12E-26
			2	0.210	0.077	0.8%	2.45E-26
			3	0.2136	0.077	0.8%	1.13E-26

Table 5-10. Summary of Deviations for CO Emissions

5.9 Exhaust Concentration Levels

Concentrations measured by PEMS and MEL are within reasonable ranges for the instruments for NO_x and CO_2. CO, THC and CH_4 are below 10% of the instruments span points. The span, audit, and average NTE measured values are shown in Tables 5-11 and 5-12, respectively, for the MEL and PEMS. The measured concentration levels for specific NTE events for the MEL and PEMS are shown in Figures 5-18 and 5-19, respectively. Note that the MEL levels represent diluted exhaust while the PEMS levels represent raw exhaust. Also, values for all tests except those on the first day of testing were used for these tables and figures, as these data are provided to show typical levels rather than detailed comparisons between the MEL and PEMS. The PEMS instrument was zeroed on ambient air while the MEL was zeroed on bottled air or nitrogen depending on the species. Ambient levels of THC were on the same order as the measured NTE exhaust levels for the MEL.

	CO ppm	CO_2 %	NO_x ppm	THC ppmC1	CH_4 ppmC1
ZERO	bottle	bottle	bottle	bottle	bottle
CAL	71.47	3.68	280.2	89.39	27.60
AUDIT	19.07	3.63/0.307	271.8	27.37	23.73
AVE NTE	1.37	2.68	137.01	1.92	2.03
STD NTE	0.64	0.39	28.68	0.49	0.18

Table 5-11. MEL calibration ranges.

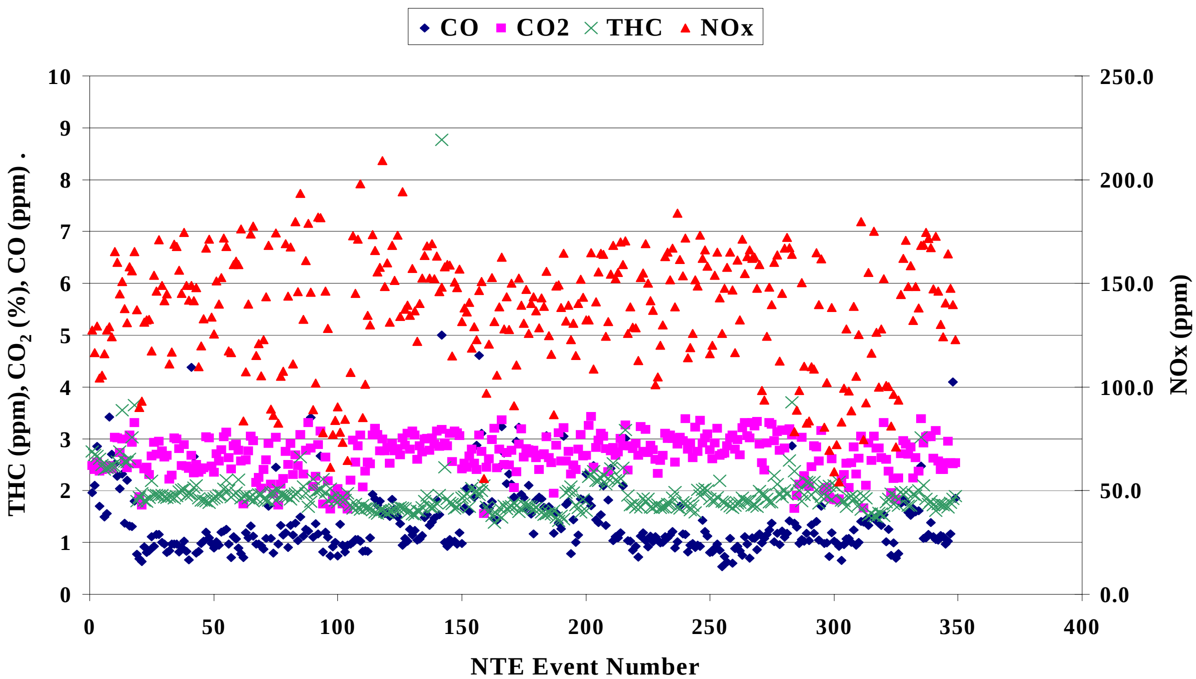


Figure 5-18. MEL Concentration Data as Measured by Instruments for All Primary Species

	CO ppm	CO_2 %	NO ppm	NO_2 ppm	THC ppm
ZERO	amb	amb	amb	amb	amb
CAL	1204	12.00	1503	253	198.0
AUDIT	200	6.03	298	60	50.5
AVE NTE	29.4	8.36	304	147	0.8
STD NTE	14.3	0.95	84	23	1.6

Table 5-12. PEMS Calibration Ranges.

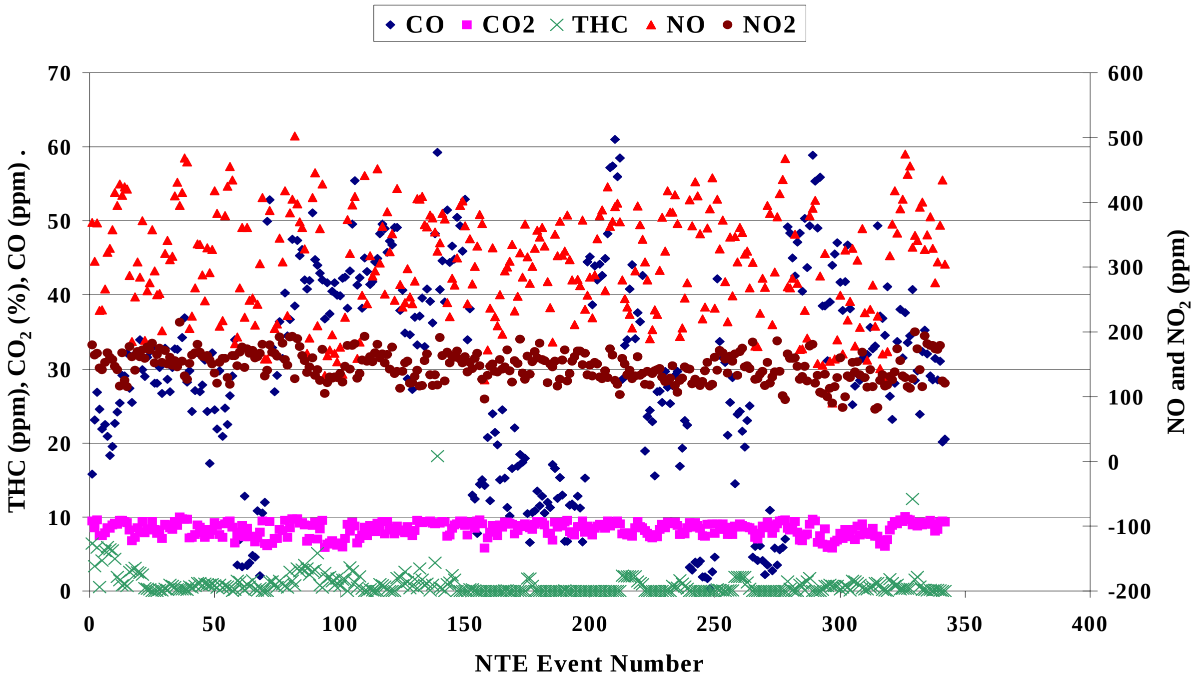


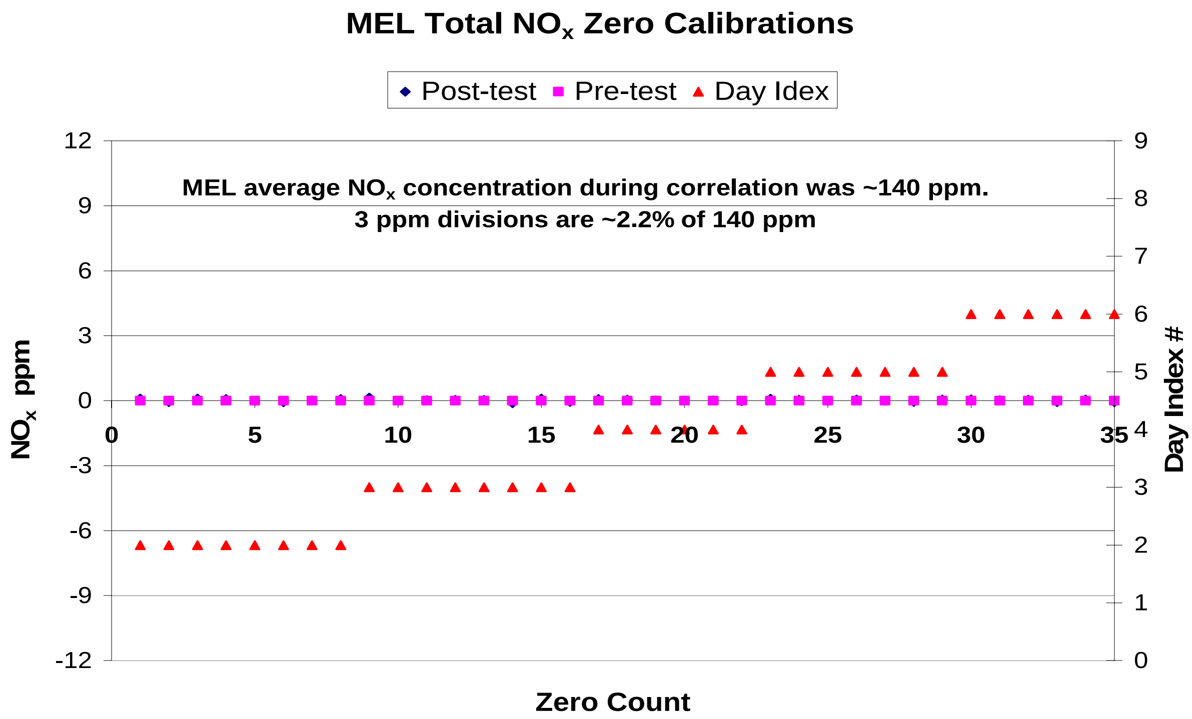
Figure 5-19. PEMs concentration data as measured by instrument for all primary species

5.10 Zero and Span Calibration Comparisons

Some additional analyses of the zero and span data through the course of the test runs was also performed as part of the evaluations for the drift limit correction and validation and to better understand the differences between the MEL and PEMS. Comparisons of pre and post zero and span data for NO_x for the MEL and PEMS are provided in Figures 5-20 and 5-21, respectively. The day index markers provide a reference as to which testing day the corresponding calibrations were conducted.

The MEL zero and spans were relatively stable over the testing period and showed little drift. It should be noted that the MEL analyzers were rezeroed and span hourly, so large drift over the testing day would not be expected. The MEL zeros showed an average drift over of the 1 hour period of less than 0.02% of the typical concentration value of 140 ppm. The span calibrations showed an average drift of 0.22%. Span drifts of over 2% were seen for only two tests with a maximum drift of 2.47%.

The PEMS showed an average pre-/post-span deviation of -0.21% with a range from -3.11% to +2.85% relative to the bottle concentration. The deviations did show greater differences relative to the average concentration levels in the exhaust with an average deviation relative to the 300 ppm concentration level of -1.04%, with a range from -15.5% to + 14.7%. The zeros also showed some drift during course of testing with an average deviation of 1.0% of the average exhaust concentration (300 ppm), but a range from -12.2% to +14.7% of 300 ppm. This could indicate that addition stabilization/purge time is needed for the zero measurements.



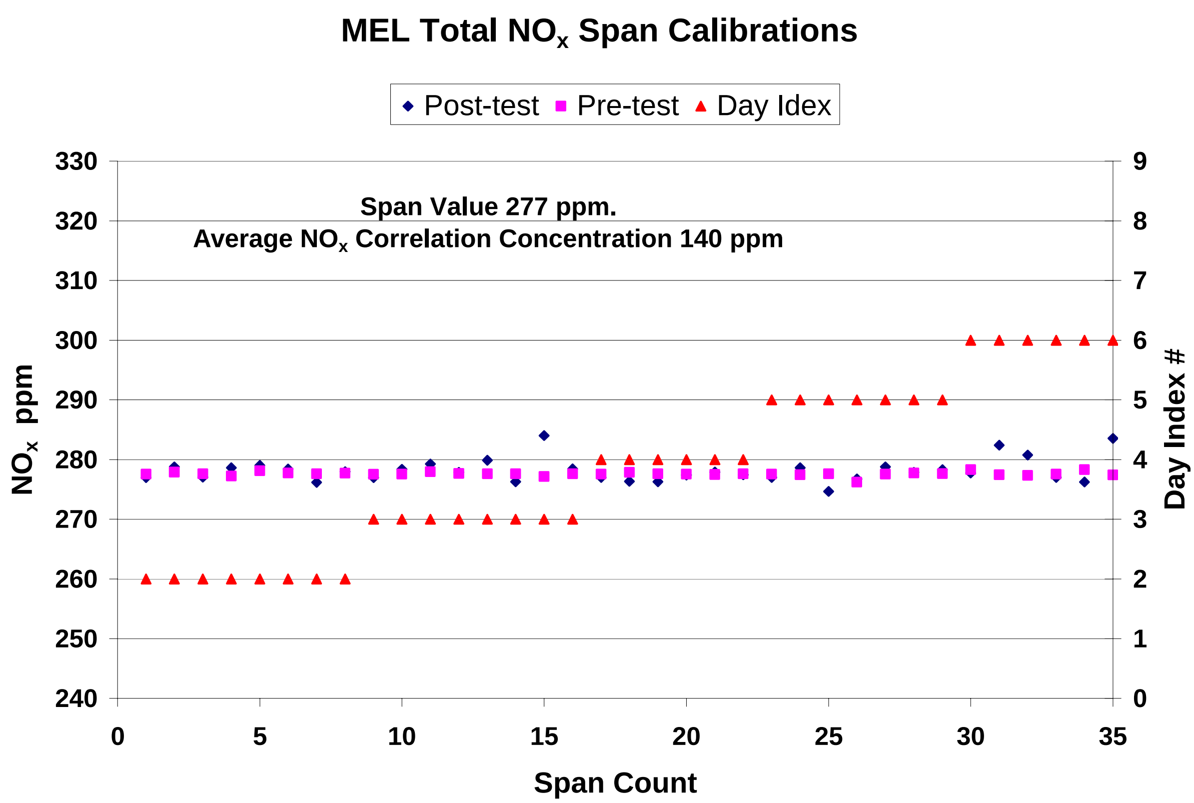
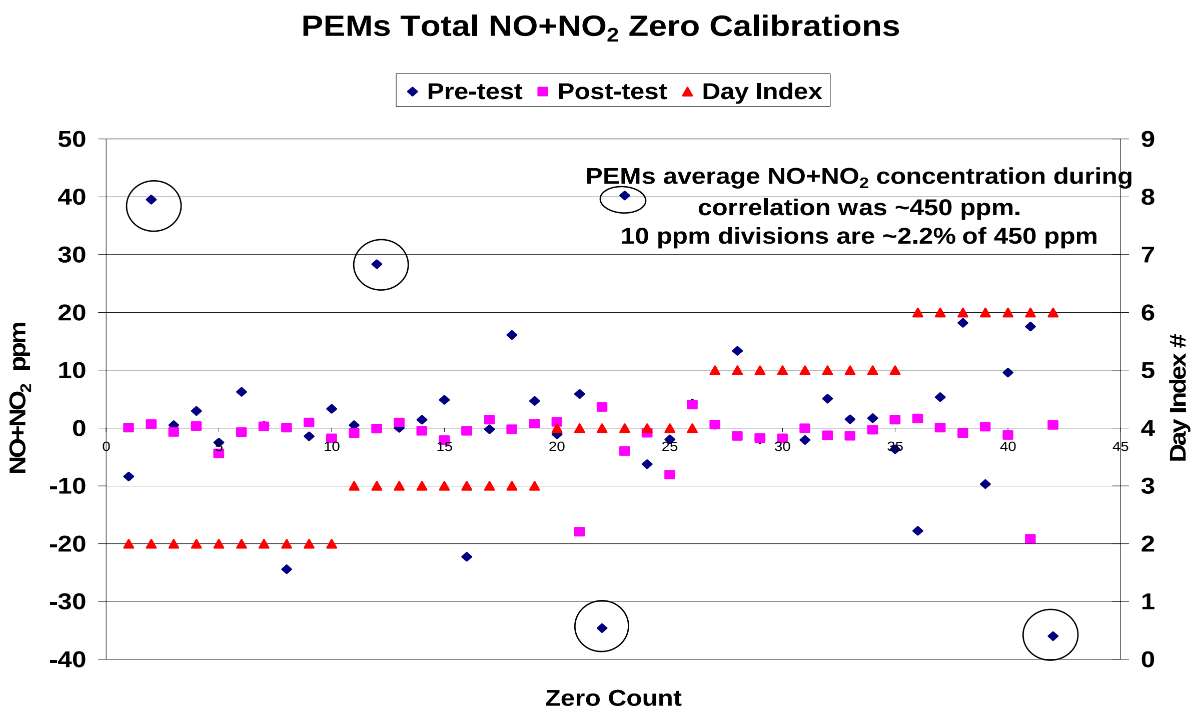


Figure 5-20. MEL Calibrations for (a) zero and (b) span.



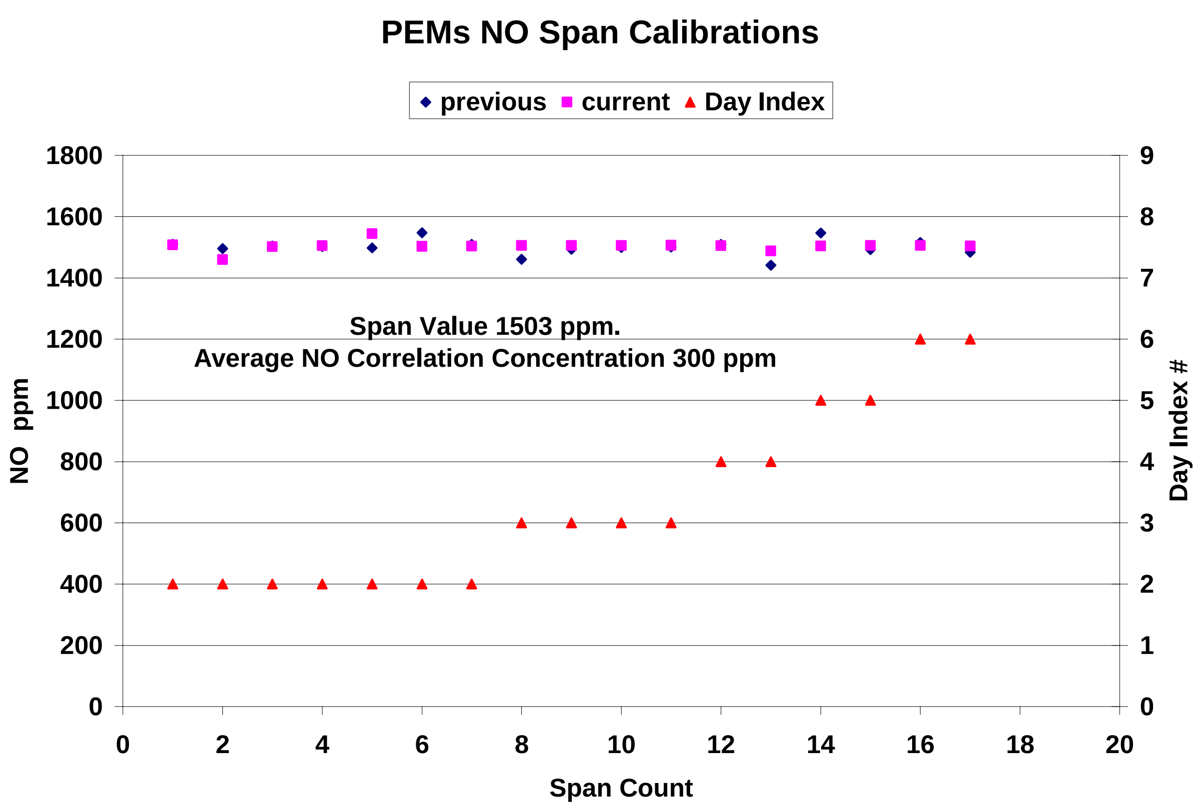


Figure 5-21. PEMS Calibrations for (a) zero and (b) span.

6.0 Summary and Conclusions

For diesel engines, soon to be implemented regulations will require the measurement of in-use emissions within the Not-To-Exceed (NTE) control area of the engine map. This will require the use of portable emissions monitoring systems (PEMS) as opposed to more traditional laboratory methods. The US EPA, CARB, and the EMA have worked together to develop a comprehensive program to determine the "allowance" for compliance purposes when PEMS are used for in-use testing. This program incorporates engine testing and environmental testing to evaluate PEMS together with a Monte Carlo simulation to evaluate and predict the anticipated error for the PEMS in the field.

An important element of this program is on-road comparisons between PEMS and the CE-CERT Mobile Emissions Laboratory (MEL), which is a full dilution tunnel system on a mobile platform. On-road comparisons were made between the MEL and the PEMS over three different courses. The courses included a trip to San Diego, CA and back, a trip from Riverside to Bishop, CA, and a trip returning to Riverside from Bishop, CA. A total of 6 test runs and 3 audits runs were conducted for the on-road testing. The runs included a trip with the PEMS positioned inside the cab, a trip with the PEMS positioned outside the cab, and a trip as an audit run without the PEMS. In conjunction with this program, a complete a cross-laboratory emissions correlation with the MEL was conducted with an engine dynamometer laboratory at the Southwest Research Institute (SwRI) in San Antonio, Texas, as well as a full 1065 audit of the MEL.

This report describes the on-road comparisons between the CE-CERT MEL and the PEMS and associated 1065 audit of the MEL and cross correlation with SwRI. The results of this study are summarized below as follows:

- As part of the validation of the CE-CERT MEL for the on-road testing, a 1065 self-audit was performed on the CE-CERT MEL. The 1065 self audit of the trailer included H_2O and CO_2 interference/quench checks, NO_2 to NO converter efficiency checks, NMHC cutter penetrations fractions. Also the linearity of all analyzers, mass flow controllers, and temperature and pressure sensors was verified. All checks were found to pass and the system to be in 1065 compliance.

- The cross correlation between an engine dynamometer test cell at SwRI and UCR's MEL represented a unique opportunity to evaluate the comparison between two 1065 compliant laboratories under the same conditions including the test engine and dynamometer, test location, and test cycles. For the NTE emissions cycle, the MEL was approximately 2% higher than the SwRI measurement for NO_x and 2.7% higher than SwRI for CO_2. For the Ramped Modal Cycle, the MEL was approximately 4% higher than the SwRI measurement for NO_x and 2.3% higher than SwRI for CO_2. These results were deemed to be acceptable to allow continuation of the on-road and engine dynamometer portions of the measurement allowance program.

- For the on-road audit runs, the measurements were compared with the audit bottle concentrations over the course of the test route. For NO_x and CO_2, the audit bottle measurements were both within 2% of the audit bottle concentration over the course of the three different test runs. THC and CO audits were within ~ 1 ppm or 5% of the audit bottle concentrations, although these bottles were at the low levels expected for a DPF equipped vehicle. Ambient levels are relatively low for NO_x and CO_2 compared to exhaust levels for these emissions. THC and CO ambient levels, on the other hand, were comparable to their exhaust sample levels for the DPF equipped vehicle.

- Over the course of the 6 test runs, a total of 426 NTE events were identified by either the MEL, the PEMS or both systems. Of these 426 events, 26 events were identified by only the MEL or PEMS, but not by both systems. For an additional 57 events, the start of the NTE events between the MEL and PEMS differed by more than 2 seconds or the duration of the NTE event differed by more than 1 second. The remaining 343 NTE events represent matching NTE events that were identified by both the MEL and the PEMS, and these events form the basis of the emissions comparisons between the MEL and PEMS.

- Brake specific emissions for NO_x, THC, and CO were calculated using three different methodologies. This included one method based on speed and torque, one method based on brake specific fuel consumption, and one method based on mass fuel flow or a fuel specific method.

- The brake specific NO_x emissions for the PEMS measurements are consistently higher than those for the MEL, with a correlation of R^2 ~0.84/0.85 between the measurements methods. The deviations were greatest for the method one calculation with an average deviation of +8%±4% relative to the NTE NO_x standard (2.0 grams per brake horsepower-hour or 2.68 grams per brake kW-hour), where the error represents one standard deviation. The deviations for methods 2 and 3 were less at +4%±5% and +3%±5%, respectively. The differences in the deviations for the different calculation methods could be related to the incorporation of CO_2 exhaust measurements into calculations 2 and 3, which are also biased high for the PEMS, or to the impacts of differences in analyzer dispersion on the calculations.

- The brake specific CO_2 emissions for the PEMS were consistently biased high relative to the MEL, with a average deviation of +4%±2%. There was a good correlation between the MEL and PEMS CO_2 measurements (R^2 = 0.97).

- NMHC emissions levels were consistently low for the on-road measurements. The average emission rates for NMHC were 0.003 g/bkW-hr or below, which is approximately 1% of the anticipated NTE standard of 0.28 g/bkW-hr. For the MEL, the diluted exhaust concentrations were comparable to those of the ambient background. There is not consistent bias for NMHC emissions between the different analyzers, with the PEMS higher for some tests and lower for others, albeit at very low levels. Average differences for the different test runs were ±0.5% or less of the NTE standard. There was a weak correlation (R^2 ~0.36/0.37) between the MEL and PEMS measurements due to the low level measurements.

- CO emissions levels were also consistently low for the on-road measurements. For the MEL, the diluted exhaust concentrations were comparable to those of the ambient background. The PEMS measurements were consistently higher than those of the MEL. The CO emissions levels were on the order of 0.1% of the anticipated NTE standard of 26.01 g/bkW-hr for CO for the MEL measurements. The absolute differences represented approximately 1% of the NTE standard, although the PEMS measurements were approximately an order of magnitude higher than those for the MEL. The correlation analysis showed that there was essentially no correlation between the measurement methods ($R^2 = 0.0011$ or less) at these low levels.

7.0 Final Measurement Allowances

The results of this study were used in the development of the measurement allowances for gaseous emissions (NO_x, THC, and CO). The measurement allowances were determined using the engine testing, environmental testing, and Monte Carlo modeling performed at SwRI, in conjunction with the validation data obtained from the CE-CERT MEL.

Initial model simulation runs showed that the model was validated by the on-road testing data only for the method 1 calculations for NO_x, for all three calculation methods for NMHC, and for none of the calculation methods for CO [Fiest et al, 2007]. The EPA and CARB continued to work with SwRI and conduct additional testing and modeling analysis in an effort to validate all three measurement methods (including method 2 and 3). This subsequent work resulted in the validation of all three methods [Buckingham and Mason, 2007]. After further discussion with the EMA and engine manufacturers, it was agreed that the newly validated and more stringent measurement allowances would be used when conducting the HDIUT program on 2010 and subsequent model year heavy-duty diesel engines (HDDEs), while the initial method 1 validated measurement allowances would still be allowed for 2007 through 2009 model year (HDDEs). The final measurement allowance values by model year are presented in Table 7-1.

Pollutant	2007 – 2009 Model Year	2010 and Subsequent Model Year
NO_x	0.45	0.15
NMHC	0.02	0.01
CO	0.50	0.25

2 Grams per brake-horsepower-hour

Table 7-1. HDIUT Measurement Allowance Values by Model Year (g/bhp-hr)[1]

8.0 References

Buckingham, J.P. and Mason, R.L. (2007) Results of HDIUT Modeling Runs Using Revised Error Surfaces. Southwest Research Institute, San Antonio, TX, June 21.

Environmental Protection Agency (2004) *Draft Technical Support Document: In-Use Testing for Heavy-Duty Diesel Engines and Vehicles*, EPA Document # 420-D-04-003, June.

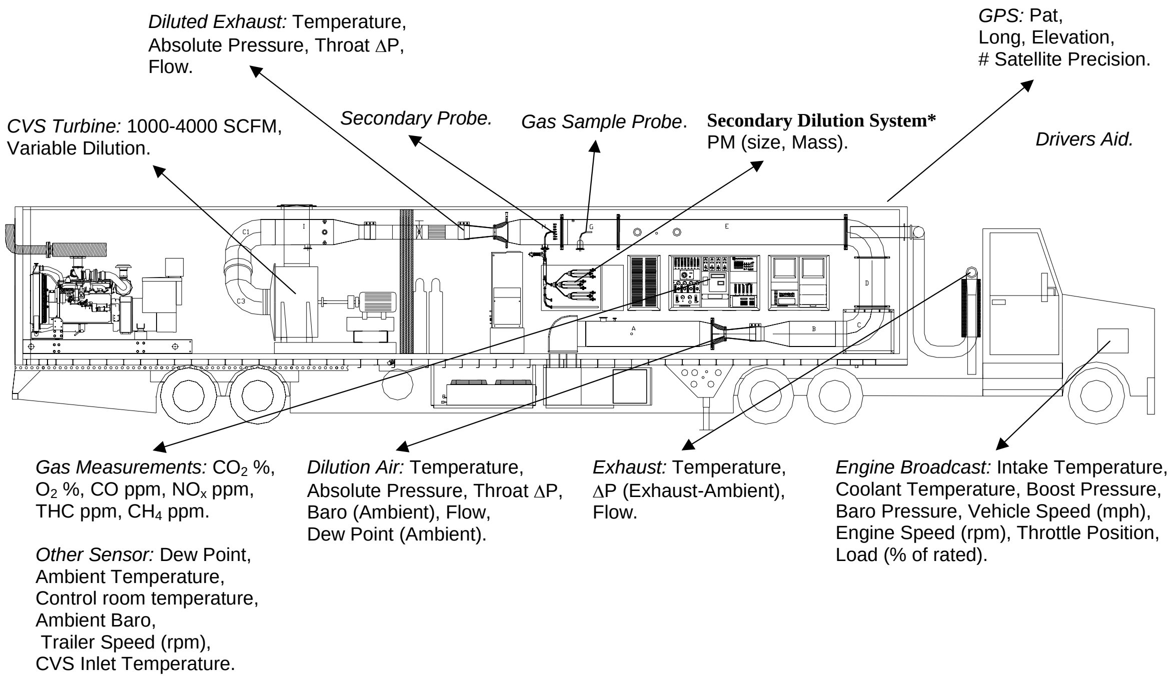
Fiest, M.D., Sharp, C.A., Mason, R.L., and Buckingham, J.P. (2007) Determination of PEMS Measurement Allowance for Gaseous Emissions Regulated Under the Heavy-Duty Diesel Engine In-Use Testing Program. Draft Final Report prepared by Southwest Research Institute, San Antonio, TX, Report # SwRI 12024, March.

Ganesan, B. and Clark, N.N. (2001) Relationships Between Instantaneous and Measured Emissions in Heavy-Duty Applications. SAE Technical Paper No. 2001-01-3536.

Truex, T.J., Collins, J.F., Jetter, J.J., Knight, B., Hayashi, T., Kishi, N., and Suzuki, N. (2000) Measurement of Ambient Roadway and Vehicle Exhaust Emissions – An Assessment of Instrument Capability and Initial On-Road Test Results with an Advanced Low Emission Vehicle. SAE Technical Paper No. 2000-01-1142.

Appendix A – Background Information on UCR's Mobile Emission Lab

Extensive detail is provided in Reference 2; so this section is provided for those that may not have access to that reference. Basically the mobile emissions lab (MEL) consists of a number of operating systems that are typically found in a stationary lab. However the MEL lab is on wheels instead of concrete. A schematic of MEL and its major subsystems is shown in the figure below. Some description follows.



Major Systems within the Mobile Emission Lab

The primary dilution system is configured as a full-flow constant volume sampling (CVS) system with a smooth approach orifice (SAO) venturi and dynamic flow controller. The SAO venturi has the advantage of no moving parts and repeatable accuracy at high throughput with low-pressure drop. As opposed to traditional dilution tunnels with a positive displacement pump or a critical flow orifice, the SAO system with dynamic flow control eliminates the need for a heat exchanger. Tunnel flow rate is adjustable from1000 to 4000 scfm with accuracy of 0.5% of full scale. It is capable of total exhaust capture for engines up to 600 hp. Colorado Engineering Experiment Station Inc. initially calibrated the flow rate through both SAOs for the primary tunnel.

The mobile laboratory contains a suite of gas-phase analyzers on shock-mounted benches. The gas-phase analytical instruments measure NO_x, methane (CH_4), total hydrocarbons (THC), CO, and CO_2 at a frequency of 10 Hz and were selected based on optimum response time and on road stability. The 200-L Tedlar bags are used to collect tunnel and dilution air samples over a complete test cycle. A total of eight bags are suspended in the MEL allowing four test cycles to be performed between analyses. Filling of the bags is automated with Lab View 7.0 software (National Instruments, Austin, TX). A summary of the analytical instrumentation used, their ranges, and principles of operation is provided in the table below. Each modal analyzer is time-corrected for tunnel, sample line, and analyzer delay time.

Gas Component	Range	Monitoring Method
NO_x	10/30/100/300/1000 (ppm)	Chemiluminescence
CO	50/200/1000/3000 (ppm)	NDIR
CO_2	0.5/2/8/16 (%)	NDIR
THC	10/30/100/300/1000 & 5000 (ppmC)	Heated FID
CH4	10/30/100/300/1000 & 5000 (ppmC)	HFID

Summary of gas-phase instrumentation in MEL

Quality Assurance and Quality Control Requirements

Internal calibration and verification procedures are performed regularly in accordance with the CFR. A partial summary of routine calibrations performed by the MEL staff as part of the data quality assurance/quality control program is listed in the table below. The MEL uses precision gas blending to obtain required calibration gas concentrations. Calibration gas cylinders, certified to 1 %, are obtained from Scott-Marrin Inc. (Riverside, CA). By using precision blending, the number of calibration gas cylinders in the lab was reduced to 5 and cylinders need to be replaced less frequently. The gas divider contains a series of mass flow controllers that are calibrated regularly with a Bios Flow Calibrator (Butler, New Jersey) and produces the required calibration gas concentrations within the required ± 1.5 percent accuracy.

In addition to weekly propane recovery checks which yield >98% recovery, CO_2 recovery checks are also performed. A calibrated mass of CO_2 is injected into the primary dilution tunnel and is measured downstream by the CO_2 analyzer. These tests also yield >98% recovery. The results of each recovery check are all stored in an internal QA/QC graph that allows for the immediate identification of problems and/or sampling bias.

An example shown below is for propane mass injected into the exhaust transfer line while sampling from raw and dilute ports (three repeats) to evaluate exhaust flow measurement on steady state basis (duration = 60 sec, Date completed January 2005).

Tests	Raw C3H8 g	Dil C3H8 g	CVS DF	Raw C3H8 est	Diff
1	2522	608	4.11	2499	-0.9%
2	2485	598	4.10	2454	-1.2%
3	2462	601	4.13	2484	0.9%
ave	2490	602	4.12	2479	-0.4%
stdev	30	5	0.01	23	
COV	1.2%	0.8%	0.3%	0.9%	

Recent example of propane quality control check

EQUIPMENT	FREQUENCY	**VERIFICATION PERFORMED**	**CALIBRATION PERFORMED**
CVS	Daily	Differential Pressure	Electronic Cal
	Daily	Absolute Pressure	Electronic Cal
	Weekly	Propane Injection	
	Monthly	CO_2 Injection	
	Per Set-up	CVS Leak Check	
	Second by second	Back pressure tolerance ±5 in$H_2$0	
Cal system MFCs	Annual	Primary Standard	MFCs: Drycal Bios Meter
	Monthly	Audit bottle check	
Analyzers	Pre/Post Test		Zero Span
	Daily	Zero span drifts	
	Monthly	Linearity Check	
Secondary System Integrity and MFCs	Semi-Annual	Propane Injection: 6 point primary vs secondary check	
	Semi-Annual		MFCs: Drycal Bios Meter & TSI Mass Meter
Data Validation	Variable	Integrated Modal Mass vs Bag Mass	
	Per test	Visual review	
PM Sample Media	Weekly	Trip Tunnel Banks	
	Monthly	Static and Dynamic Blanks	
Temperature	Daily	Psychrometer	Performed if verification fails
Barometric Pressure	Daily	Aneroid barometer ATIS	Performed if verification fails
Dewpoint Sensors	Daily	Psychrometer Chilled mirror	Performed if verification fails

Sample of Verification and Calibration Quality Control Activities

Appendix B – Description of PEMS Instrument

SEMTECH-DS is a complete, fully integrated portable emissions measurement system (PEMS) for testing all classes of vehicles and equipment under real-world operating conditions. SEMTECH-DS measures emissions at the tailpipe, engine-out, or at any stage of after-treatment from vehicles powered by diesel, biodiesel, gasoline, CNG, propane, and even hydrogen fuel. A data logger records the vehicle emissions, environmental conditions, and the output of a vehicle's on-board electronic control system to compact flash removable storage while the vehicle is in operation. The optional exhaust mass flowmeter and GPS are also fully integrated with the SEMTECH-DS data logger and post-processing software. Engine and vehicle-related parameters are combined with gaseous emissions on a real-time basis to determine in-use emissions levels in g/sec, g/g-fuel, g/Bhp-hr, and g/mile. Not to Exceed (NTE) vehicle operation and emissions results are also determined on a real-time basis. Test results can also be viewed subsequently with the user-configurable post-processor application.

Access to the central processor is provided through LabView™ PC host software. The user interface is designed to provide immediate feedback to the user. There are over 150 different fault codes that the SEMTECH will automatically report to the user if a problem occurs. In addition, there are 24 warning codes that will also automatically be reported when potential problems exist. They indicate to the user when to change filters, when to change the FID fuel bottle, when to zero the instrument. In addition, many of the routine tasks that are required to operate the system are fully automated, requiring minimal effort for the user.

The SEMTECH-DS system comprises of eight individual analyzers, all integrated into a single package and controlled from a central processor/data logger. The following table describes the subcomponents and system features.

SEMTECH-D Subsystem	**Specifications**
Sample Line & Filter	Heated (191 ^oC)
THC	Heated FID (191 ^oC), Wet sample measurement, autoranging, max 4 Hz data rate
NO_2	NDUV resonant absorption spectroscopy
NO	NDUV resonant absorption spectroscopy
CO and CO_2	CO and CO2 through NDIR spectroscopy
O_2	Electrochemical Cell
Methane	Unheated FID with cutter, external to SEMTECH
Exhaust flow rate and temperature	Sensors Exhaust Flow Meter (averaging Pitot tube)
Vehicle speed and position	Garmin 16-HVS GPS, WAAS supported
Ambient temperature, relative humidity, barometric pressure	Vaisla remote temperature and humidity monitor; on-board barometric pressure sensor, max 4 Hz data rate
Vehicle Interface (VI) Protocols	Heavy-Duty: SAE-J1708, SAE-J1939 Light-Duty: SAE-J1850 VPW, SAE-J1850 PWM, ISO-9141-2, ISO-14230-4, ISO-11898, ISO-15765
Engine torque	VI (if available from equipment's CAN/ECM)
Engine RPM	VI (if available from equipment's CAN/ECM), or through use of an optical tachometer probe on mechanically-controlled equipment
Air-fuel ratio	Determined per ISO 16183 carbon balance method
Size	14"H x 17"W x 22"D
Weight	approximately 75 lbs

SEMTECH-D Subsystem	Specifications
Communications	Wired and wireless Ethernet, 8.0211g
Host Software	Sensor Tech suite using Labview™
Analog output	8-channels, 0 – 5V
Analog input	3-channels, ±5V, ±10V, ±10V with programmable transform functions
Digital input	2-channel
Digital output	1-channel
Data Storage	Up to 1 Gb Compact Flash cards. Adequate to hold one full week of data.
Data rate	Configurable 1 – 4 Hz for most channels

Appendix C – Test File Names and Descriptions

Test File Name	Description
200610030817.XML	*In-cab Route 1 Riverside to San Diego*: Session manager not setup properly. Figured out for Route 2 and on. All in-cab Route 1 have individual tests sessions. In-cab Route 2 and later tests have one session for the day.
200610030910.XML	*In-cab Route 1 Riverside to San Diego*: Session manager not setup properly.
200610031016.XML	*In-cab Route 1 Riverside to San Diego*: Session manager not setup properly.
200610031117.XML	*In-cab Route 1 Riverside to San Diego*: Software hang-up prevented pre FID bottle change zero, span and audit test. Post bottle swap zero span audit test was successful.
200610031247.XML	*In-cab Route 1 Riverside to San Diego*: Software hang-up prevented pre FID bottle change zero, span and audit test. Post bottle swap zero span audit test was successful.
ROUTE2A.XML	*In-cab Route 2 Riverside to Mammoth*. Part A. FID bottle change one hour before end of test. Successful pre and post FID bottle change zero, span, and audit test.
ROUTE2B.XML	*In-cab Route 2 Riverside to Mammoth*. Part B. FID bottle change one hour before end of test. Successful pre and post FID bottle change zero, span, and audit test.
ROUTE3A.XML	*In-cab Route 3 Mammoth to Riverside*. Part A. FID bottle change one hour before end of test. Successful pre and post FID bottle change zero, span, and audit test. 2 hour to warm up because power from engine.
ROUTE3B.XML	*In-cab Route 3 Mammoth to Riverside*. Part B. FID bottle change one hour before end of test. Successful pre and post FID bottle change zero, span, and audit test.
ROUTE1OUT.XML	*Out-of-cab Route 1 Riverside to San Diego*: Took more than two hours to warm up because power supplied by batteries (12.6 volts). Moved to generator power with committee approval. No FID bottle change.
ROUTE2OUT.XML	*Out of cab Route 2 Riverside to Mammoth*. Power supplied by generator power. No FID bottle change.
ROUTE3OUT.XML	*Out of cab Route 3 Mammoth to Riverside*. Power supplied by generator power. No FID bottle change.

Appendix D – Brake Specific Emissions Calculations

Notes:

1. The PEMS sample data file contains the information necessary to perform the three brake-specific emission calculations as stated in the work assignment. After a discussion with Matt Spears (EPA) we have modified the emission equations as shown below.
2. The ECM fuel rate is broadcast in L/hr, so we will need to convert that measurement into g/s with density data for the fuel. The fuel density is 851.0 g/L.
3. The PEMS sample data did not include NMHC or ECM fuel rate. These values were estimated and added to the file. It is still unclear what the units of some of the channels will be as we do not have a recent PEMS sample file.
4. CO_2 error surfaces were added for all steady state, transient and environmental tests.
5. In calculation methods #2 and #3, assume HC=NMHC (i.e., 0.98*THC = NMHC).

METHOD #1 EQUATIONS

Data from reference NTE event:

1. Exhaust flow rate (scfm)
2. Emission Concentration: NO(ppm), NO_2(ppm), CO(%), NMHC(ppm)
   NOTE: Compute NMHC = 0.98 * THC from reference NTE.
3. Fuel rate (L/h)
4. Speed (rpm)
5. Torque values (N·m)

Convert *exhaust flow rate* from SCFM to mol/s:

$$\dot{n}_i\left(\frac{mol}{s}\right)=\frac{\dot{n}_i(SCFM)*\frac{1}{35.31467}\left(\frac{m^3}{ft^3}\right)*\frac{1}{60}\left(\frac{\min}{s}\right)*101325(Pa)}{293.15(K)*8.314472\left(\frac{J}{mol*K}\right)}$$

Brake Specific NOx Calculation for Method #1

$$\Delta t = 1\,(\sec)$$

$$M_{NO_2} = 46.0055\left(\frac{g}{mol}\right)$$

$$e_{NO_x}\left(g / kW \cdot hr\right) = \frac{M_{NO_2} * \sum_{i=1}^{N}\left[\left(xNO_{2_i}\left(ppm\right) + xNO_i\left(ppm\right)\right) * 10^{-6} * \dot{n}_i\left(\frac{mol}{s}\right) * \Delta t\right]}{\sum_{i=1}^{N}\left[\frac{Speed_i\left(rpm\right) * T_i\left(N \cdot m\right) * 2 * 3.14159 * \Delta t}{60 * 1000 * 3600}\right]}$$

In the MC simulation, the following deltas (error surface number) will be added to the above parameters:

xNO_2 + xNO	<=	SS (1) + TR (2) + EMI (3) + Pressure (4) + Temp (5) + Shock/Vib (6)
Exhaust Flow	<=	SS (20) + TR (21) + Pulse (22) + Swirl (23) + Wind (24) + EMI (25) + Shock/Vib (26) + Temp (27) + Pressure (28)
Torque	<=	DOE (30) + Warm-up (31) + Humidity (32) + Fuel (33) + Manuf (35)
Speed	<=	Dynamic Speed (43)

Brake Specific CO Calculation for Method #1

$$\Delta t = 1\,(\sec)$$

$$M_{CO} = 28.0101\left(\frac{g}{mol}\right)$$

$$e_{CO}\left(g / kW \cdot hr\right) = \frac{M_{CO} * \sum_{i=1}^{N}\left[\left(xCO_i\left(\%\right)\right) * 10^{-2} * \dot{n}_i\left(\frac{mol}{s}\right) * \Delta t\right]}{\sum_{i=1}^{N}\left[\frac{Speed_i\left(rpm\right) * T_i\left(N \cdot m\right) * 2 * 3.14159 * \Delta t}{60 * 1000 * 3600}\right]}$$

In the MC simulation, the following deltas (error surface number) will be added to the above parameters:

xCO	<=	SS (7) + TR (8) + EMI (9) + Pressure (10) + Temp (11) + Shock/Vib (12)
Exhaust Flow	<=	SS (20) + TR (21) + Pulse (22) + Swirl (23) + Wind (24) + EMI (25) + Shock/Vib (26) + Temp (27) + Pressure (28)
Torque	<=	DOE (30) + Warm-up (31) + Humidity (32) + Fuel (33) + Manuf (35)
Speed	<=	Dynamic Speed (43)

Brake Specific NMHC Calculation for Method #1

$$\Delta t = 1\,(\sec)$$

$$M_{NMHC} = 13.875389\left(\frac{g}{mol}\right)$$

$$e_{NMHC}(g/kW \cdot hr) = \frac{M_{NMHC} * \sum_{i=1}^{N}\left[\left(xNMHC_i(ppm)\right) * 10^{-6} * \dot{n}_i\left(\frac{mol}{s}\right) * \Delta t\right]}{\sum_{i=1}^{N}\left[\frac{Speed_i(rpm) * T_i(N \cdot m) * 2 * 3.14159 * \Delta t}{60 * 1000 * 3600}\right]}$$

In the MC simulation, the following deltas (error surface number) will be added to the above parameters:

xNMHC	<=	SS (13) + TR (14) + EMI (15) + Pressure (16) + Temp (17) + Shock/Vib (18) + Ambient (19)
Exhaust Flow	<=	SS (20) + TR (21) + Pulse (22) + Swirl (23) + Wind (24) + EMI (25) + Shock/Vib (26) + Temp (27) + Pressure (28)
Torque	<=	DOE (30) + Warm-up (31) + Humidity (32) + Fuel (33) + Manuf (35)
Speed	<=	Dynamic Speed (43)

Method #2 Equations

Data from reference NTE event:

1. Exhaust flow rate (scfm)
2. Emission Concentration: NO(ppm), NO_2(ppm), CO(%), CO_2(%), NMHC(ppm)
   NOTE: NMHC = 0.98 * THC from the reference NTE
3. Fuel rate (L/h)
4. Speed (rpm)
5. BSFC values (g/kW·hr)

Convert *exhaust flow rate* from SCFM to mol/s:

$$\dot{n}_i\left(\frac{mol}{s}\right)=\frac{\dot{n}_i(SCFM)*\frac{1}{35.31467}\left(\frac{m^3}{ft^3}\right)*\frac{1}{60}\left(\frac{\min}{s}\right)*101325(Pa)}{293.15(K)*8.314472\left(\frac{J}{mol*K}\right)}$$

<u>Brake Specific NOx Concentration for Method #2</u>

$$w_{fuel}=0.869 \quad \textit{Mass fraction of carbon in the fuel.}$$

$$\Delta t=1\,(\text{sec})$$

$$M_C=12.0107\left(\frac{g}{mol}\right)$$

$$M_{NO_2}=46.0055\left(\frac{g}{mol}\right)$$

$$e_{NO_x}(g/kW\cdot hr)=\frac{M_{NO_2}*\sum_{i=1}^{N}\left[\left(xNO_{2_i}(ppm)+xNO_i(ppm)\right)*10^{-6}*\dot{n}_i\left(\frac{mol}{s}\right)*\Delta t\right]}{\frac{M_C}{w_{fuel}}*\sum_{i=1}^{N}\left[\frac{\dot{n}_i\left(\frac{mol}{s}\right)*\left[xNMHC_i(ppm)*10^{-6}+\left(xCO_i(\%)+xCO_{2_i}(\%)\right)*10^{-2}\right]*\Delta t}{BSFC_i\left(\frac{g}{kW\cdot hr}\right)}\right]}$$

In the MC simulation, the following deltas (error surface number) will be added to the above parameters:

$xNO_2 + xNO$	<=	SS (1) + TR (2) + EMI (3) + Pressure (4) + Temp (5) + Shock/Vib (6)
xCO	<=	SS (7) + TR (8) + EMI (9) + Pressure (10) + Temp (11) + Shock/Vib (12)
xNMHC	<=	SS (13) + TR (14) + EMI (15) + Pressure (16) + Temp (17) + Shock/Vib (18) + Ambient (19)
Exhaust Flow	<=	SS (20) + TR (21) + Pulse (22) + Swirl (23) + Wind (24) + EMI (25) + Shock/Vib (26) + Temp (27) + Pressure (28)
BSFC	<=	DOE (37) + Warm-up (38) + Humidity (39) + Fuel (40) + Manuf (42)
xCO2	<=	SS (45) + TR (46) + EMI (47) + Pressure (48) + Temp (49) + Shock/Vib (50)

<u>Brake Specific CO Concentration for Method #2</u>

$$w_{fuel} = 0.869 \quad \textit{Mass fraction of carbon in the fuel.}$$

$$\Delta t = 1\,(\sec)$$

$$M_C = 12.0107\left(\frac{g}{mol}\right)$$

$$M_{CO} = 28.0101\left(\frac{g}{mol}\right)$$

$$e_{CO}(g/kW\cdot hr) = \frac{M_{CO} * \sum_{i=1}^{N}\left[\left(xCO_i(\%)\right) * 10^{-2} * \dot{n}_i\left(\frac{mol}{s}\right) * \Delta t\right]}{\frac{M_C}{w_{fuel}} * \sum_{i=1}^{N}\left[\frac{\dot{n}_i\left(\frac{mol}{s}\right) * \left[xNMHC_i(ppm) * 10^{-6} + \left(xCO_i(\%) + xCO_{2_i}(\%)\right) * 10^{-2}\right] * \Delta t}{BSFC_i\left(\frac{g}{kW\cdot hr}\right)}\right]}$$

In the MC simulation, the following deltas (error surface number) will be added to the above parameters:

xCO	<=	SS (7) + TR (8) + EMI (9) + Pressure (10) + Temp (11) + Shock/Vib (12)
xNMHC	<=	SS (13) + TR (14) + EMI (15) + Pressure (16) + Temp (17) + Shock/Vib (18) + Ambient (19)
Exhaust Flow	<=	SS (20) + TR (21) + Pulse (22) + Swirl (23) + Wind (24) + EMI (25) + Shock/Vib (26) + Temp (27) + Pressure (28)
BSFC	<=	DOE (37) + Warm-up (38) + Humidity (39) + Fuel (40) + Manuf (42)

xCO2	<=	SS (45) + TR (46) + EMI (47) + Pressure (48) + Temp (49) + Shock/Vib (50)

Brake Specific NMHC Concentration for Method #2

$$w_{fuel} = 0.869 \quad \textit{Mass fraction of carbon in the fuel.}$$

$$\Delta t = 1\,(\sec)$$

$$M_C = 12.0107\left(\frac{g}{mol}\right)$$

$$M_{NMHC} = 13.875389\left(\frac{g}{mol}\right)$$

$$e_{NMHC}(g / kW \cdot hr) = \frac{M_{NMHC} * \sum_{i=1}^{N}\left[\left(xNMHC_i\,(ppm)\right) * 10^{-6} * \dot{n}_i\left(\frac{mol}{s}\right) * \Delta t\right]}{\frac{M_C}{w_{fuel}} * \sum_{i=1}^{N}\left[\frac{\dot{n}_i\left(\frac{mol}{s}\right) * \left[xNMHC_i\,(ppm) * 10^{-6} + \left(xCO_i\,(\%) + xCO_{2_i}\,(\%)\right) * 10^{-2}\right] * \Delta t}{BSFC_i\left(\frac{g}{kW \cdot hr}\right)}\right]}$$

In the MC simulation, the following deltas (error surface number) will be added to the above parameters:

xCO	<=	SS (7) + TR (8) + EMI (9) + Pressure (10) + Temp (11) + Shock/Vib (12)
xNMHC	<=	SS (13) + TR (14) + EMI (15) + Pressure (16) + Temp (17) + Shock/Vib (18) + Ambient (19)
Exhaust Flow	<=	SS (20) + TR (21) + Pulse (22) + Swirl (23) + Wind (24) + EMI (25) + Shock/Vib (26) + Temp (27) + Pressure (28)
BSFC	<=	DOE (37) + Warm-up (38) + Humidity (39) + Fuel (40) + Manuf (42)
xCO2	<=	SS (45) + TR (46) + EMI (47) + Pressure (48) + Temp (49) + Shock/Vib (50)

Method #3 Equations

Data from reference NTE event:

1. Exhaust flow rate (scfm)
2. Emission Concentration: NO(ppm), NO_2(ppm), CO(%), CO_2(%), NMHC(ppm)
   NOTE: NMHC = 0.98 * THC from the reference NTE
3. Fuel rate (L/h)
4. Speed (rpm)
5. Torque values (N·m)

<u>Brake Specific NOx Concentration for Method #3</u>

$$w_{fuel} = 0.869 \quad \textit{Mass fraction of carbon in the fuel.}$$

$$M_C = 12.0107\left(\frac{g}{mol}\right)$$

$$M_{NO_2} = 46.0055\left(\frac{g}{mol}\right)$$

$$\Delta t = 1\,(\text{sec})$$

Example mass fuel mass rate calculation:

$$\dot{m}_{fuel_i}\left(\frac{g}{s}\right) = Fuelrate_i\left(\frac{L}{hr}\right) * 851.0\left(\frac{g}{L}\right) * \frac{1}{3600}\left(\frac{hr}{s}\right)$$

$$e_{NO_x}(g/kW\cdot hr) = \frac{\dfrac{M_{NO_2} * w_{fuel}}{M_C} * \displaystyle\sum_{i=1}^{N}\left[\frac{\left(xNO_{2_i}(ppm) + xNO_i(ppm)\right)*10^{-6} * \dot{m}_{fuel\,i}\left(\frac{g}{s}\right)}{xNMHC_i(ppm)*10^{-6} + \left(xCO_i(\%) + xCO_{2_i}(\%)\right)*10^{-2}} * \Delta t\right]}{\displaystyle\sum_{i=1}^{N}\left[\frac{Speed_i(rpm)*T_i(N\cdot m)*2*3.14159*\Delta t}{60*1000*3600}\right]}$$

In the MC simulation, the following deltas (error surface number) will be added to the above parameters:

xNO_2 + xNO	<=	SS (1) + TR (2) + EMI (3) + Pressure (4) + Temp (5) + Shock/Vib (6)
xCO	<=	SS (7) + TR (8) + EMI (9) + Pressure (10) + Temp (11) + Shock/Vib (12)
xNMHC	<=	SS (13) + TR (14) + EMI (15) + Pressure (16) + Temp (17) + Shock/Vib (18) + Ambient (19)

Torque	<=	DOE (30) + Warm-up (31) + Humidity (32) + Fuel (33) + Manuf (35)
Speed	<=	Dynamic Speed (43)
Fuel Rate	<=	Dynamic Fuel Rate (44)
xCO2	<=	SS (45) + TR (46) + EMI (47) + Pressure (48) + Temp (49) + Shock/Vib (50)

<u>Brake Specific CO Concentration for Method #3</u>

$$w_{fuel} = 0.869 \quad \textit{Mass fraction of carbon in the fuel.}$$

$$M_C = 12.0107\left(\frac{g}{mol}\right)$$

$$M_{CO} = 28.0101\left(\frac{g}{mol}\right)$$

$$\Delta t = 1\,(\mathrm{sec})$$

$$\textit{Example mass fuel mass rate calculation:}$$

$$\dot{m}_{fuel_i}\left(\frac{g}{s}\right) = Fuelrate_i\left(\frac{L}{hr}\right)*851.0\left(\frac{g}{L}\right)*\frac{1}{3600}\left(\frac{hr}{s}\right)$$

$$e_{CO}(g/kW\cdot hr) = \frac{\dfrac{M_{CO}*w_{fuel}}{M_C}*\displaystyle\sum_{i=1}^{N}\left[\frac{(xCO_i(\%))*10^{-2}*\dot{m}_{fuel_i}\left(\frac{g}{s}\right)}{xNMHC_i(ppm)*10^{-6}+\left(xCO_i(\%)+xCO_{2_i}(\%)\right)*10^{-2}}*\Delta t\right]}{\displaystyle\sum_{i=1}^{N}\left[\frac{Speed_i(rpm)*T_i(N\cdot m)*2*3.14159*\Delta t}{60*1000*3600}\right]}$$

In the MC simulation, the following deltas (error surface number) will be added to the above parameters:

xCO	<=	SS (7) + TR (8) + EMI (9) + Pressure (10) + Temp (11) + Shock/Vib (12)
xNMHC	<=	SS (13) + TR (14) + EMI (15) + Pressure (16) + Temp (17) + Shock/Vib (18) + Ambient (19)
Torque	<=	DOE (30) + Warm-up (31) + Humidity (32) + Fuel (33) + Manuf (35)
Speed	<=	Dynamic Speed (43)
Fuel Rate	<=	Dynamic Fuel Rate (44)
xCO2	<=	SS (45) + TR (46) + EMI (47) + Pressure (48) + Temp (49) + Shock/Vib (50)

Brake Specific NMHC Concentration for Method #3

$$w_{fuel} = 0.869 \quad \textit{Mass fraction of carbon in the fuel.}$$

$$M_C = 12.0107\left(\frac{g}{mol}\right)$$

$$M_{NMHC} = 13.875389\left(\frac{g}{mol}\right)$$

$$\Delta t = 1\,(\mathrm{sec})$$

Example mass fuel mass rate calculation:

$$\dot{m}_{fuel_i}\left(\frac{g}{s}\right) = Fuelrate_i\left(\frac{L}{hr}\right) * 851.0\left(\frac{g}{L}\right) * \frac{1}{3600}\left(\frac{hr}{s}\right)$$

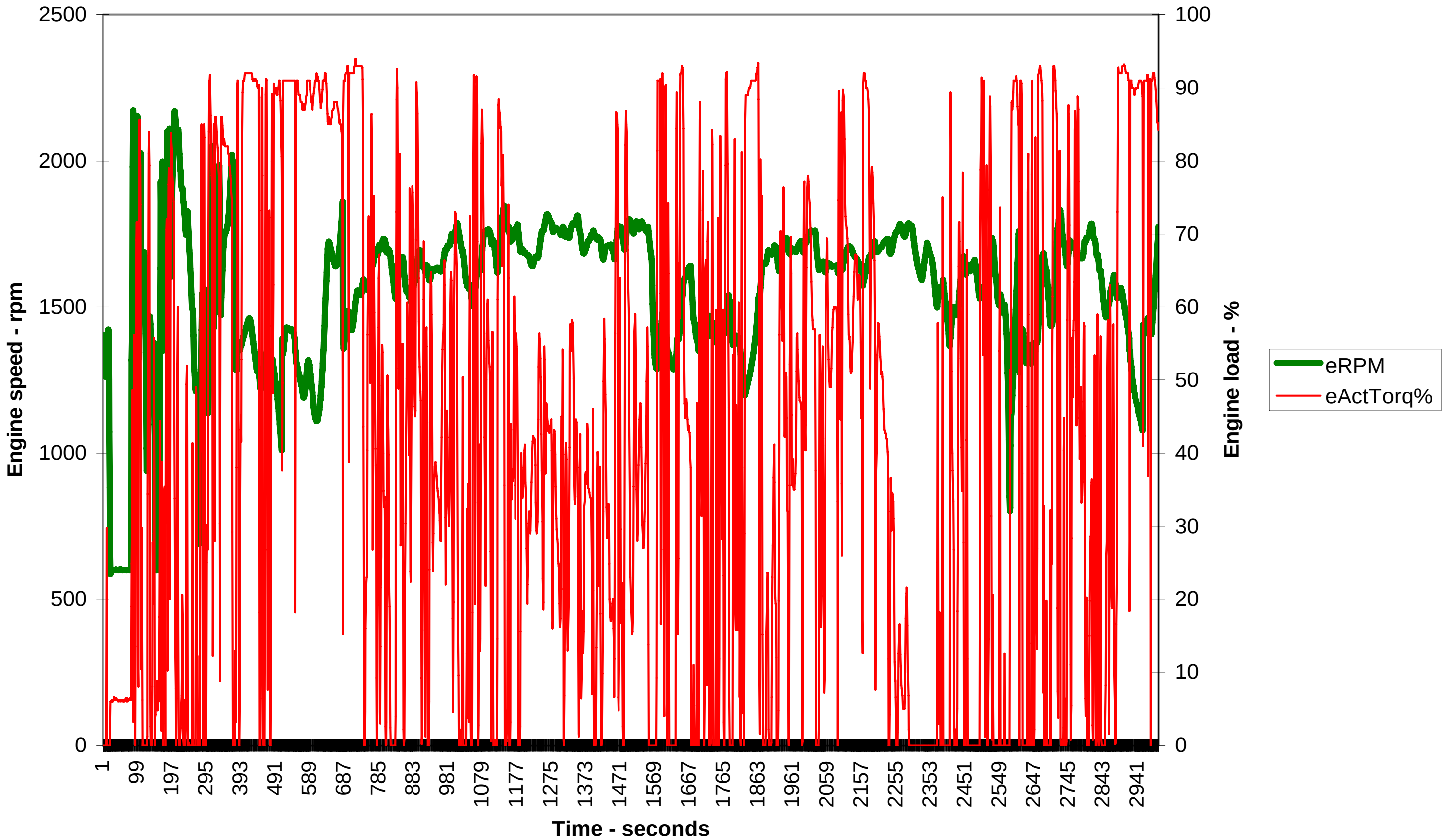
$$e_{NMHC}(g/kW\cdot hr) = \frac{\dfrac{M_{NMHC} * w_{fuel}}{M_C} * \displaystyle\sum_{i=1}^{N}\left[\frac{\left(xNMHC_i\,(ppm)\right)*10^{-6} * \dot{m}_{fuel\,i}\left(\frac{g}{s}\right)}{xNMHC_i\,(ppm)*10^{-6} + \left(xCO_i\,(\%) + xCO_{2_i}\,(\%)\right)*10^{-2}} * \Delta t\right]}{\displaystyle\sum_{i=1}^{N}\left[\frac{Speed_i\,(rpm)*T_i\,(N\cdot m)*2*3.14159*\Delta t}{60*1000*3600}\right]}$$

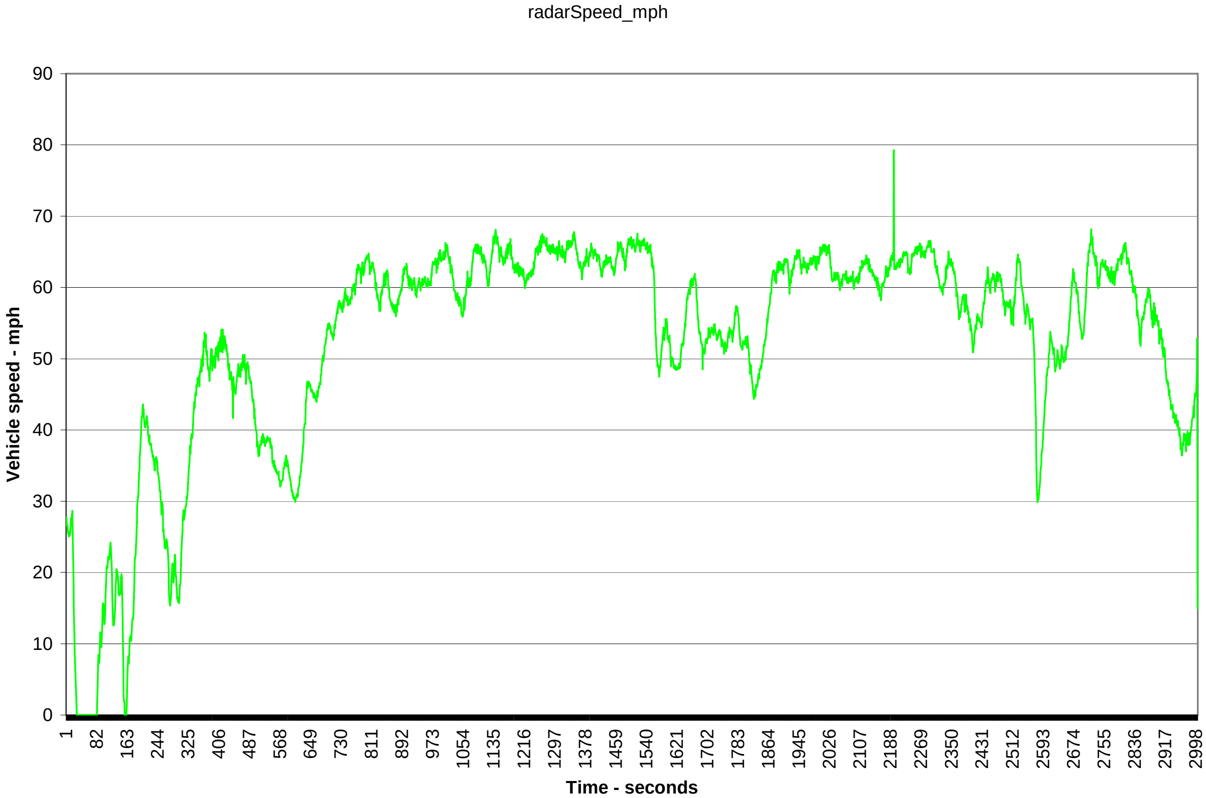
In the MC simulation, the following deltas (error surface number) will be added to the above parameters:

xCO	<=	SS (7) + TR (8) + EMI (9) + Pressure (10) + Temp (11) + Shock/Vib (12)
xNMHC	<=	SS (13) + TR (14) + EMI (15) + Pressure (16) + Temp (17) + Shock/Vib (18) + Ambient (19)
Torque	<=	DOE (30) + Warm-up (31) + Humidity (32) + Fuel (33) + Manuf (35)
Speed	<=	Dynamic Speed (43)
Fuel Rate	<=	Dynamic Fuel Rate (44)
xCO2	<=	SS (45) + TR (46) + EMI (47) + Pressure (48) + Temp (49) + Shock/Vib (50)

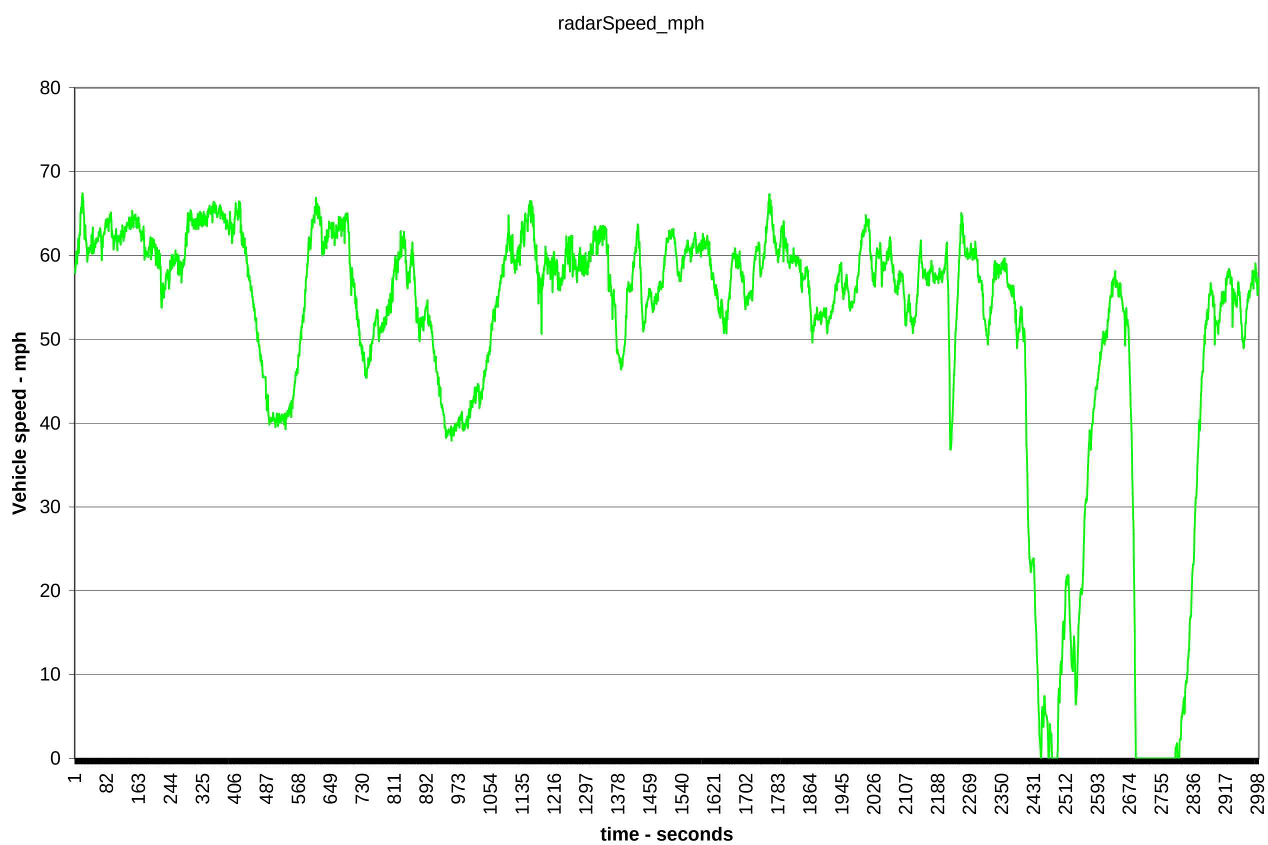
Appendix E – Vehicle/Engine Speed and Torque Traces for Test Runs

CE-CERT MAP over-the-road data run 200610030910

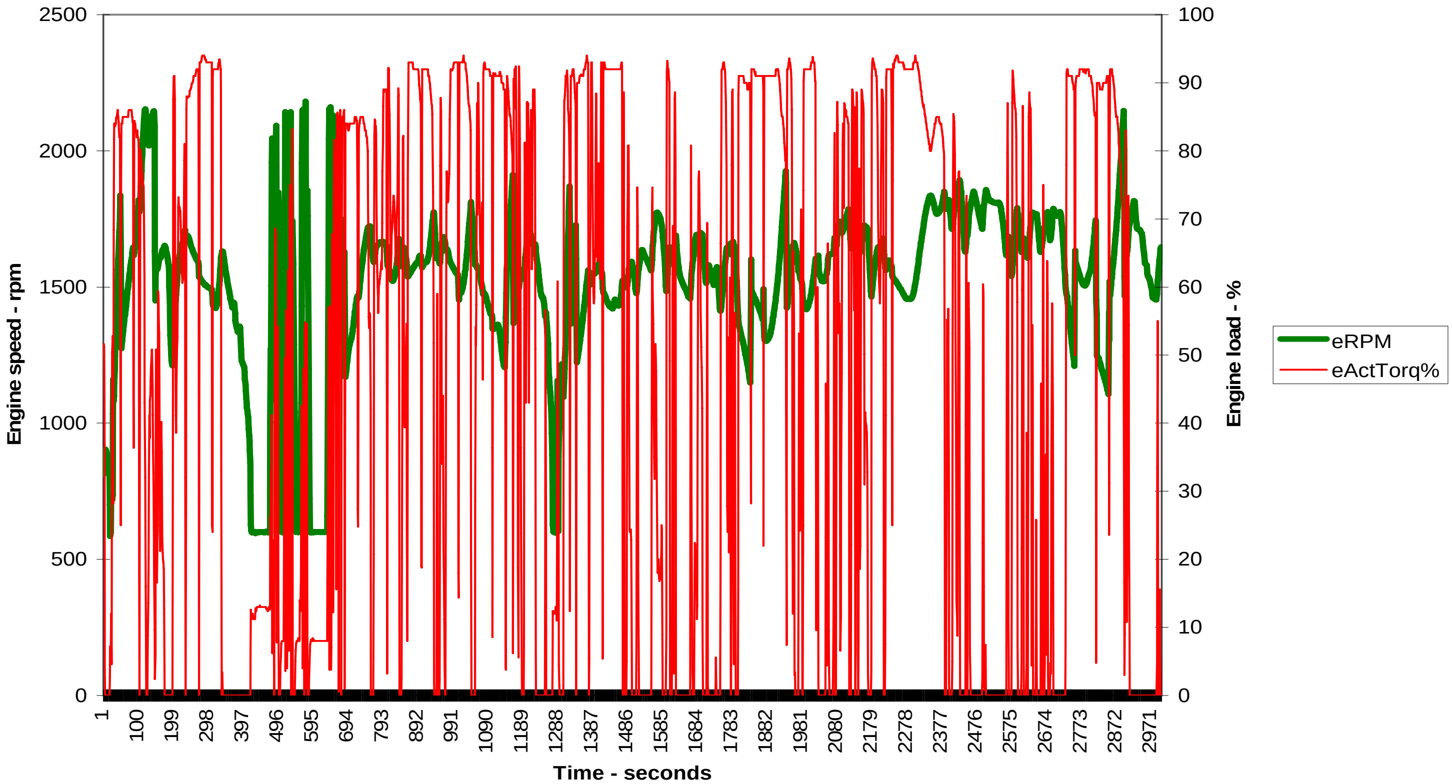




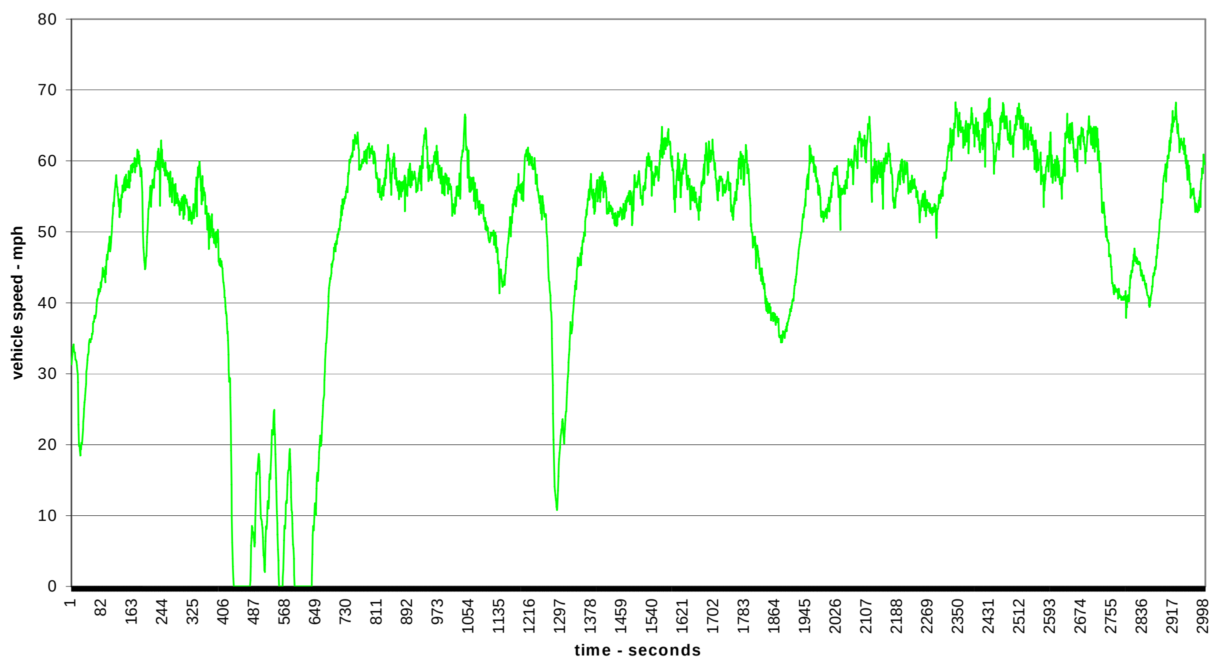
CE-CERT MAP over-the-road data run 200610031016



CE-CERT MAP over-the-road data - run 200610031117



radarSpeed_mph



Appendix F – Summary Table of Average Vehicle and Engine Speeds and Torques

rec #	run no		eng spd	eng torque	veh e-spd	veh r-spd		eng spd	eng torque	veh e-spd	veh r-spd
1	200610030910	avg	1557	42.72	48.13	52.85	std dev	241	33.88	13.58	14.95
2	200610031016	avg	1520	37.31	46.99	51.19	std dev	278	36.69	14.93	16.20
3	200610031117	avg	1524	49.38	46.69	50.20	std dev	284	39.17	14.82	15.72
4	200610031247	avg	1403	42.61	39.17	42.83	std dev	413	35.84	22.87	25.15
5	200610041004	avg	1570	58.97	43.41	47.10	std dev	244	36.42	14.28	15.42
6	200610041105	avg	1238	26.76	33.24	36.64	std dev	497	31.06	25.75	28.37
7	200610041237	avg	1476	46.95	40.63	44.82	std dev	418	36.38	21.83	23.96
8	200610041338	avg	1732	50.11	58.14	64.03	std dev	172	30.76	6.87	7.63
9	200610041438	avg	1733	38.55	57.19	63.09	std dev	213	27.22	9.20	10.03
10	200610041628	avg	1570	43.09	42.92	47.25	std dev	265	34.20	15.70	17.19
11	200610050703	avg	1511	37.80	37.32	41.10	std dev	334	34.89	16.52	18.10
12	200610050807	avg	1587	41.60	51.54	56.75	std dev	289	25.97	13.98	15.37
13	200610050907	avg	1758	44.32	59.37	65.44	std dev	126	33.46	4.25	4.66
14	200610051009	avg	1665	56.52	54.14	59.55	std dev	127	36.05	8.04	8.80
15	200610051233	avg	1563	50.51	45.29	49.72	std dev	318	34.89	17.00	18.62
16	200610051335	avg	1279	18.66	31.45	34.04	std dev	516	27.05	25.51	27.71
17	200610100845	avg	1605	42.52	50.11	54.70	std dev	299	32.99	15.71	17.41
18	200610100952	avg	1460	32.82	42.06	45.85	std dev	300	35.23	17.41	18.89
19	200610101053	avg	1511	44.74	44.88	48.19	std dev	340	38.44	18.33	19.55
20	200610101221	avg	1549	47.92	48.50	53.13	std dev	295	35.32	16.63	18.37
21	200610110924	avg	1522	57.91	38.46	41.67	std dev	337	35.32	17.78	19.15
22	200610111027	avg	1392	33.23	38.99	42.82	std dev	522	32.00	26.02	28.54
23	200610111150	avg	1754	52.38	57.12	62.85	std dev	138	32.89	8.78	9.60
24	200610111300	avg	1710	51.22	55.98	61.77	std dev	194	32.05	8.32	9.13
25	200610111401	avg	1295	28.06	33.82	37.16	std dev	562	29.91	28.11	30.87
26	200610111501	avg	1628	44.58	45.84	50.34	std dev	291	33.86	16.61	18.08
27	200610120600	avg	1607	40.87	44.09	48.51	std dev	238	33.53	13.34	14.51
28	200610120705	avg	1674	36.42	55.02	60.58	std dev	180	24.67	8.96	9.78
29	200610120805	avg	1799	35.27	60.75	66.94	std dev	124	27.13	4.18	4.55
30	200610120905	avg	1464	37.63	44.54	49.13	std dev	376	36.64	19.98	22.05
31	200610121047	avg	1474	48.66	42.43	46.66	std dev	337	34.93	17.49	19.19
32	200610121148	avg	1394	15.97	36.32	39.34	std dev	483	25.43	22.88	24.83
	32-run average		**1548**	**42**	**46.08**	**50.51**		**305**	**33**	**15.80**	**17.26**
	32-run std dev		141.47	10.19	8.08	9.02		121.03	3.87	6.34	6.94
rec #	**run no**		**avg eng spd**	**avg eng torque**	**avg veh e-spd**	**avg veh r-spd**		**std dev eng spd**	**std dev eng torque**	**std dev veh e-spd**	**std dev veh r-spd**

Appendix G – NO_x Emissions by NTE Event and Calculation Method

Shaded areas are where drift correction failed

Unique ID for NTE event	MEL Meth 1 NOx g/kWhr	PEMS Meth 1 NOx g/kWhr	MEL Meth 2 NOx g/kWhr	PEMS Meth 2 NOx g/kWhr	MEL Meth 3 NOx g/kWhr	PEMS Meth 3 NOx g/kWhr	MEL start	PEMS start	MEL dur	PEMS dur_	MEL bhp	PEMS bhp
10041004_1	3.40	3.91	3.62	3.92	3.65	3.98	379	376	38	39	3.176	3.166
10041004_2	3.35	3.79	3.59	3.97	3.59	3.97	419	416	38	38	2.946	2.929
10041004_3	3.40	3.79	3.67	3.89	3.69	3.90	530	528	34	33	2.884	2.833
10041004_4	3.28	3.79	3.52	3.94	3.52	3.94	648	646	77	76	5.445	5.363
10041004_5	3.37	3.83	3.59	3.96	3.60	3.96	798	796	34	33	2.376	2.326
10041004_6	3.32	3.75	3.60	3.94	3.63	3.94	867	864	32	32	2.487	2.478
10041004_7	3.55	3.96	3.82	4.12	3.87	4.12	918	915	44	44	3.527	3.516
10041004_8	3.56	4.04	3.84	4.18	3.86	4.20	964	961	38	39	3.078	3.073
10041004_9	3.45	3.91	3.73	4.06	3.77	4.06	1006	1003	50	51	4.018	4.014
10041004_10	3.82	4.30	4.13	4.48	4.13	4.48	1094	1092	136	135	13.11	13.02
10041004_11	3.76	4.24	4.08	4.43	4.09	4.43	1243	1240	135	136	12.79	12.77
10041004_12	3.58	4.11	3.87	4.18	3.89	4.18	1379	1377	106	378	9.515	34.12
10041004_13	3.66	#N/A	3.85	#N/A	1.49	#N/A	1486	#N/A	271	#N/A	24.64	#N/A
10041004_14	3.57	4.07	3.85	4.21	3.86	4.21	1957	1955	82	142	6.8	11.42
10041004_15	3.59	#N/A	3.80	#N/A	3.81	#N/A	2040	#N/A	59	#N/A	4.619	#N/A
10041004_16	3.81	4.38	3.95	4.41	4.03	4.43	2100	2098	55	55	4.893	4.856
10041004_17	3.71	4.50	3.97	4.64	3.98	4.64	2157	2154	82	277	7.385	24.32
10041004_18	4.00	#N/A	4.30	#N/A	4.31	#N/A	2240	#N/A	194	#N/A	17.01	#N/A
10041105_1	3.64	3.91	4.06	4.09	4.13	4.08	615	613	37	37	2.952	2.939
10041105_2	3.46	3.70	3.69	3.83	3.68	3.82	772	769	35	36	1.927	1.948
10041105_3	3.60	3.74	3.95	3.91	4.08	3.91	1151	1149	36	35	1.969	1.935
10041105_4	3.48	3.73	3.83	3.85	3.88	3.86	1300	1298	45	45	3.567	3.542
10041105_5	3.59	3.92	4.05	4.13	4.15	4.12	1415	1413	42	42	3.249	3.202
10041105_6	3.47	3.88	3.87	3.95	3.92	3.96	1470	1467	35	65	2.791	5.451
10041237_1	3.34	3.43	3.59	3.53	3.60	3.52	208	205	73	73	5.302	5.248
10041237_2	3.69	3.80	4.07	3.92	4.15	3.93	294	291	47	47	4.057	4.023
10041237_3	3.70	3.81	4.00	3.98	4.10	3.99	353	351	40	39	3.263	3.212
10041237_4	3.62	3.70	3.97	3.83	3.99	3.83	412	409	63	63	6.103	6.07
10041237_5	3.62	3.69	3.94	3.84	3.95	3.84	498	495	91	91	7.646	7.597
10041237_6	3.81	3.94	4.08	4.06	4.14	4.06	700	698	34	34	2.567	2.551
10041237_7	3.59	3.69	3.99	3.81	4.03	3.80	926	924	34	34	2.772	2.765
10041237_8	3.67	3.69	4.05	3.85	4.11	3.85	963	961	40	103	2.451	6.546
10041237_9	3.61	#N/A	3.95	#N/A	3.96	#N/A	1004	#N/A	63	#N/A	4.125	#N/A
10041237_10	3.63	3.73	4.08	3.88	4.13	3.89	1070	1068	35	34	3.31	3.246
10041237_11	3.72	3.81	4.12	3.99	4.13	3.99	1129	1126	104	105	9.539	9.547
10041237_12	3.63	3.70	4.00	3.86	4.02	3.86	1302	1299	93	93	8.152	8.083
10041237_13	3.76	3.81	4.24	4.00	4.26	3.99	1400	1398	36	36	2.835	2.814
10041237_14	3.83	3.90	4.20	4.06	4.23	4.06	1437	1435	68	67	6.314	6.254
10041237_15	#N/A	4.24	#N/A	4.44	#N/A	4.43	#N/A	1517	#N/A	35	#N/A	3.096
10041237_16	3.72	#N/A	4.02	#N/A	4.07	#N/A	2603	#N/A	30	#N/A	2.455	#N/A
10041237_17	3.65	3.93	3.93	3.97	3.94	3.97	2639	2636	52	52	4.121	4.103
10041237_18	3.68	3.93	3.91	3.97	3.91	3.97	2692	2690	102	101	8.414	8.35
10041237_19	3.73	4.05	4.05	4.11	4.09	4.11	2795	2792	32	60	2.471	4.753
10041237_20	3.56	3.81	3.96	3.99	3.98	3.99	2869	2867	63	62	5.326	5.253

10041338_1	3.38	3.69	3.70	3.87	3.71	3.87		210	207	35	36	2.329	2.354
10041338_2	3.58	3.86	3.85	4.04	3.85	4.04		270	267	80	80	5.495	5.467
10041338_3	3.64	3.98	4.08	4.19	4.15	4.19		355	352	36	36	2.697	2.656
10041338_4	3.62	3.84	3.97	3.99	4.02	3.98		422	419	33	33	3.118	3.088
10041338_5	3.90	4.14	4.30	4.28	4.35	4.29		671	668	37	37	3.323	3.294
10041338_6	3.58	3.84	3.93	4.06	4.02	4.07		826	823	48	48	3.674	3.647
10041338_7	3.77	4.00	4.11	4.21	4.16	4.21		919	916	37	38	2.532	2.568
10041338_8	3.75	4.03	4.06	4.22	4.06	4.22		1003	1000	148	148	12.23	12.2
10041338_9	3.86	4.19	4.21	4.43	4.24	4.43		1181	1178	101	102	7.526	7.494
10041338_10	3.97	4.31	4.40	4.52	4.43	4.53		1285	1282	34	34	2.686	2.668
10041338_11	3.80	4.10	4.16	4.30	4.17	4.30		1321	1319	151	151	14.04	13.99
10041338_12	3.80	4.08	4.15	4.25	4.15	4.25		1480	1477	63	63	5.709	5.684
10041338_13	3.42	3.71	3.71	3.83	3.75	3.84		1680	1677	36	36	2.527	2.511
10041338_14	3.69	4.04	3.99	4.20	4.00	4.20		1814	1812	113	112	7.293	7.19
10041338_15	3.65	3.96	4.02	4.18	4.03	4.18		1957	1954	91	92	8.107	8.11
10041338_16	3.78	4.09	4.04	4.19	4.06	4.20		2050	2047	65	66	5.631	5.635
10041338_17	3.69	3.96	4.06	4.15	4.06	4.16		2117	2114	134	135	11.77	11.78
10041338_18	4.34	4.59	4.88	4.83	4.94	4.83		2825	2822	35	35	2.908	2.866
10041338_19	3.55	3.90	3.77	4.11	3.78	4.10		2904	2902	36	34	1.725	1.635
10041438_1	3.52	3.87	3.59	3.88	3.59	3.87		13	11	34	34	2.108	2.091
10041438_2	3.74	4.12	4.10	4.30	4.18	4.34		54	51	38	39	2.9	2.899
10041438_3	3.91	4.20	4.23	4.41	4.23	4.42		217	214	57	58	5.157	5.176
10041438_4	#N/A	3.98	#N/A	4.19	#N/A	4.17		#N/A	288	#N/A	30	#N/A	1.875
10041438_5	4.03	4.31	4.42	4.57	4.42	4.56		1074	1071	34	35	3.04	3.052
10041438_6	3.59	3.88	3.99	4.13	4.00	4.13		1132	1130	34	34	2.224	2.207
10041438_7	3.75	4.01	4.09	4.24	4.12	4.24		1290	1288	43	43	2.821	2.793
10041438_8	4.00	4.34	4.37	4.60	4.38	4.60		1340	1338	36	35	1.924	1.871
10041438_9	3.89	4.16	4.09	4.43	n/a	4.43		1496	1493	58	59	3.719	3.737
10041438_10	4.12	4.44	4.59	4.73	4.63	4.74		1557	1555	41	35	2.889	2.555
10041438_11	3.81	4.11	4.17	4.34	4.19	4.34		1924	1922	44	43	3.945	3.894
10041438_12	4.19	4.50	4.17	4.41	4.17	4.41		2210	2207	50	50	2.159	2.131
10041438_13	4.26	4.61	4.31	4.65	4.31	4.65		2415	2413	60	59	2.459	2.397
10041438_14	3.88	4.15	4.23	4.31	4.25	4.32		2786	2784	45	45	4.08	4.063
10041628_1	3.68	4.04	3.87	4.17	3.87	4.17		9	7	38	37	1.717	1.675
10041628_2	3.52	3.79	3.83	3.95	3.84	3.95		94	91	34	34	2.048	2.022
10041628_3	3.86	4.20	4.08	4.28	4.08	4.28		162	139	42	63	2.366	3.656
10041628_4	4.31	4.61	4.69	4.82	4.70	4.83		279	277	47	46	3.72	3.667
10041628_5	3.79	4.11	4.18	4.29	4.18	4.29		370	367	32	32	2.451	2.424
10041628_6	3.73	3.95	4.05	4.13	4.06	4.13		1136	1134	165	164	15.01	14.94
10041628_7	3.47	3.76	3.74	3.92	3.74	3.91		1403	1400	37	38	2.372	2.38
10041628_8	4.51	4.66	5.04	4.98	5.05	4.98		1708	1706	34	33	2.736	2.701
10041628_9	3.69	3.80	3.89	3.88	3.93	3.89		1757	1747	33	40	2.625	3.102
10041628_10	4.29	4.54	4.63	4.67	4.66	4.70		1791	1788	420	420	37.86	37.81
10050703_1	3.52	3.71	3.72	3.82	3.80	3.82		132	130	35	34	2.685	2.648
10050703_2	3.58	3.69	3.88	3.89	3.91	3.90		169	166	34	35	3.11	3.125
10050703_3	3.94	4.14	4.16	4.28	4.19	4.29		358	356	36	36	3.293	3.295
10050703_4	3.49	3.68	3.72	3.80	3.77	3.81		396	393	43	43	3.622	3.603
10050703_5	3.07		3.24		3.25			557		148		8.686	
10050703_6	3.12		3.33		3.34			708		63		4.169	
10050703_7	4.10	4.14	4.35	4.36	4.35	4.36		852	849	43	43	3.873	3.846

10050703_8	3.93	4.29	4.19	4.41	4.22	4.42		896	893	434	435	40.38	40.34
10050703_9	2.97	3.28	3.13	3.44	3.14	3.44		2006	2004	34	34	1.816	1.795
10050703_10	3.55	3.76	3.81	3.93	3.84	3.92		2329	2327	31	30	2.592	2.554
10050807_1	3.69	3.91	3.89	3.96	3.91	3.96		212	210	33	33	2.341	2.333
10050807_2	3.04	3.24	3.12	3.32	3.12	3.31		445	443	35	34	1.442	1.393
10050807_3	3.28	3.49	3.38	3.57	3.38	3.57		521	518	60	60	2.887	2.867
10050807_4	3.20	3.44	3.39	3.58	3.40	3.57		586	583	57	57	3.059	3.027
10050807_5	3.26	3.50	3.42	3.61	3.42	3.60		800	797	45	45	2.54	2.516
10050807_6	3.32	3.55	3.41	3.64	3.41	3.63		866	864	69	68	3.309	3.25
10050807_7	3.27	3.52	3.36	3.61	3.36	3.60		940	938	103	102	4.679	4.603
10050807_8	3.33	3.60	3.47	3.72	3.47	3.72		1046	1043	169	169	8.688	8.613
10050807_9	3.16	3.41	3.22	3.48	3.22	3.48		1256	1254	48	47	1.996	1.945
10050807_10	3.49	3.73	3.67	3.86	3.67	3.85		1308	1306	163	161	10.17	10.03
10050807_11	3.78	4.01	4.07	4.16	4.07	4.16		1472	1469	75	75	6.993	6.978
10050807_12	3.93	4.07	4.19	4.22	4.27	4.23		1791	1788	35	35	2.643	2.609
10050807_13	3.77	3.92	4.10	4.07	4.12	4.07		1830	1827	36	36	3.345	3.336
10050807_14	4.50	4.54	4.86	4.89	4.89	4.91		1958	1955	30	30	2.697	2.674
10050807_15	3.23	3.44	3.40	3.57	3.40	3.56		2071	2068	101	101	5.455	5.422
10050807_16	3.23	3.43	3.45	3.54	3.45	3.54		2248	2246	81	80	5.193	5.126
10050807_17	3.86	4.06	4.13	4.20	4.15	4.21		2408	2405	63	63	4.508	4.478
10050807_18	3.79	5.07	4.06	5.49	4.09	5.48		2549	2514	47	30	3.305	2.734
10050807_19	#N/A	3.96	#N/A	4.12	#N/A	4.12		#N/A	2546	#N/A	47	#N/A	3.305
10050907_1	3.73	3.91	4.03	3.97	4.04	3.98		1	1	34	93	3.258	8.534
10050907_2	3.73	#N/A	4.02	#N/A	4.06	#N/A		36	#N/A	61	#N/A	5.57	#N/A
10050907_3	3.59	3.73	3.87	3.82	3.88	3.82		189	186	73	73	6.5	6.493
10050907_4	4.07	4.28	4.52	4.46	4.57	4.49		313	310	54	55	4.311	4.309
10050907_5	4.62	4.69	5.05	4.82	5.06	4.82		421	419	40	39	3.732	3.678
10050907_6	3.49	3.63	3.80	3.72	3.80	3.71		613	611	36	36	3.158	3.13
10050907_7	3.64	3.70	3.92	3.79	3.93	3.79		756	753	89	89	8.053	8.044
10050907_8	3.63	3.78	3.92	3.93	3.95	3.93		869	866	62	62	4.615	4.592
10050907_9	3.65	3.80	3.98	3.92	3.99	3.92		938	935	111	112	10.55	10.54
10050907_10	3.70	3.91	4.06	4.07	4.10	4.07		1064	1061	79	79	6.663	6.625
10050907_11	4.06	4.28	4.53	4.49	4.58	4.50		1235	1232	47	48	4.134	4.148
10050907_12	3.74	3.90	4.03	4.01	4.09	4.03		1700	1697	31	32	2.293	2.311
10050907_13	4.22	4.37	4.66	4.51	4.67	4.52		2335	2332	34	35	3.255	3.253
10050907_14	3.66	3.70	3.88	3.74	3.92	3.78		2657	2654	38	38	2.979	2.961
10050907_15	3.49	3.63	3.66	3.64	3.69	3.64		2809	2806	55	56	4.602	4.602
10051009_1	3.54	3.73	3.80	3.88	3.83	3.89		16	13	73	74	5.909	5.889
10051009_2	3.54	3.71	3.86	3.87	3.88	3.87		96	93	47	47	4.431	4.403
10051009_3	3.54	3.68	3.72	3.73	3.75	3.73		145	142	74	75	6.053	6.066
10051009_4	3.59	3.80	3.87	3.92	3.88	3.92		254	251	41	41	2.95	2.919
10051009_5	3.49	3.66	3.81	3.82	3.82	3.81		297	295	47	47	4	3.953
10051009_6	3.53	3.70	3.85	3.83	3.86	3.83		347	344	102	103	9.327	9.317
10051009_7	3.66	3.76	3.97	3.93	3.97	3.93		452	449	322	323	30.62	30.59
10051009_8	3.71	3.81	4.05	4.00	4.06	4.00		776	774	209	208	20.15	20.09
10051009_9	3.62	3.65	3.90	3.82	3.92	3.82		1213	1210	83	49	7.432	4.36
10051009_10	3.89	3.85	4.06	3.92	4.12	3.92		1297	1260	40	74	3.7	6.757
10051009_11	3.57	3.72	3.80	3.79	3.81	3.79		1339	1336	88	88	7.987	7.949
10051009_12	3.96	4.13	4.17	4.20	4.19	4.20		1428	1426	62	62	5.449	5.443
10051009_13	3.66	3.86	3.88	3.94	3.91	3.94		1545	1543	47	47	3.984	3.973

10051233_1	3.56	3.71	3.70	3.75	3.73	3.74	54	52	34	33	3.028	2.958
10051233_2	3.65	3.92	3.96	4.13	3.97	4.13	89	87	96	101	8.9	9.222
10051233_3	3.63	3.87	4.00	4.09	4.01	4.09	194	191	127	128	11.88	11.88
10051233_4	3.69	3.89	3.87	3.93	3.89	3.93	322	320	116	115	10.65	10.57
10051233_5	#N/A	4.17	#N/A	4.41	#N/A	4.43	#N/A	923	#N/A	34	#N/A	2.384
10051233_6	3.55	4.00	3.87	4.12	3.92	4.15	964	962	33	32	2.278	2.215
10051233_7	3.54	3.92	3.81	4.05	3.84	4.05	1018	1015	52	52	4.68	4.635
10051233_8	3.49	3.72	3.76	3.80	3.79	3.78	2299	2297	30	30	2.692	2.67
10051233_9	3.59	3.74	3.85	3.86	3.87	3.87	2629	2626	44	44	4.067	4.018
10051233_10	3.44	3.71	3.73	3.89	3.75	3.89	2724	2722	78	77	6.297	6.233
10051233_11	3.45	3.74	3.77	3.90	3.78	3.91	2838	2835	82	83	6.941	6.965
10051233_12	3.52	3.84	3.92	4.07	3.97	4.06	2951	2948	36	36	2.938	2.936
10051335_1	#N/A	3.75	#N/A	3.94	#N/A	3.93	#N/A	1870	#N/A	32	#N/A	2.398
10051335_2	3.39	3.51	3.73	3.64	3.74	3.64	1988	1985	37	37	3.353	3.348
10100845_1	3.38	3.66	3.49	3.65	3.50	3.64	91	92	36	33	2.827	2.752
10100845_2	3.45		3.77		3.77		183		41		3.417	
10100845_3	3.51	3.55	3.72	3.66	3.73	3.66	262	261	148	53	11.53	3.97
10100845_4	#N/A	3.83	#N/A	3.86	#N/A	3.86	#N/A	315	#N/A	93	#N/A	7.487
10100845_5	3.51	3.83	3.75	3.95	3.76	3.96	411	409	59	116	5.486	10.61
10100845_6	3.60	#N/A	3.97	#N/A	3.98	#N/A	471	#N/A	55	#N/A	5.133	#N/A
10100845_7	2.83		3.06		3.07		1241		33		1.44	
10100845_8	3.26		3.46		3.49		1415		37		2.432	
10100845_9	3.30		3.60		3.62		1541		45		3.632	
10100845_10	3.61		3.91		3.95		1735		36		3.362	
10100845_11	3.25		3.51		3.53		1790		44		3.93	
10100845_12	3.15		3.48		3.50		1847		55		4.076	
10100845_13	3.48		3.76		3.76		2543		75		6.611	
10100845_14	3.86		4.07		4.07		2619		36		3.353	
10100952_1	3.31		3.66		3.67		60		59		5.063	
10100952_2	3.55	3.42	3.84	3.55	3.87	3.55	121	120	76	59	6.816	5.216
10100952_3	3.51		3.80		3.81		230		164		13.26	
10100952_4	3.68		4.10		4.12		396		38		3.442	
10100952_5	3.27	3.72	3.53	3.88	3.53	3.87	1141	1145	35	34	2.167	2.131
10100952_6	3.19	3.45	3.44	3.57	3.44	3.56	1608	1612	35	40	2.695	2.942
10100952_7	3.58	3.96	3.87	4.13	3.92	4.13	1644	1654	34	34	3.222	3.214
10100952_8	3.46	3.87	3.58	3.89	3.58	3.89	2235	2244	41	42	3.69	3.689
10100952_9	3.30	3.70	3.60	3.81	3.62	3.81	2700	2709	36	37	3.21	3.212
10101053_1	3.58	3.68	3.89	3.86	3.89	3.85	21	18	91	91	8.382	8.373
10101053_2	3.29	3.55	3.52	3.63	3.53	3.62	634	631	41	42	3.497	3.506
10101053_3	3.56	3.78	3.87	4.00	3.88	3.99	726	707	51	68	4.497	5.838
10101053_4	3.44	3.66	3.78	3.92	3.80	3.93	828	826	39	39	3.641	3.637
10101053_5	3.40	3.68	3.74	3.86	3.75	3.86	918	916	85	85	7.622	7.607
10101053_6	3.47	3.73	3.82	3.88	3.83	3.90	1177	1174	39	39	3.201	3.179
10101053_7	3.48	3.71	3.83	3.92	3.85	3.92	1249	1246	65	65	5.903	5.896
10101053_8	3.43	3.79	3.74	3.91	3.74	3.91	1621	1618	50	117	4.501	10.7
10101053_9	3.64	#N/A	3.80	#N/A	3.83	#N/A	1672	#N/A	65	#N/A	6.179	#N/A
10101053_10	3.40	3.69	3.74	3.92	3.77	3.92	1769	1766	48	49	3.901	3.919
10101053_11	3.30	3.61	3.57	3.81	3.60	3.81	1896	1894	55	54	4.279	4.194
10101053_12	3.18	3.48	3.48	3.69	3.49	3.68	1979	1977	55	54	3.316	3.252
10101053_13	3.52	3.74	3.83	3.91	3.84	3.91	2036	2033	108	108	10.1	10.06

10101053_14	3.50	3.71	3.86	3.93	3.87	3.92		2145	2143	43	43	4.045	4.023
10101053_15	3.56	3.65	3.92	3.86	3.92	3.84		2521	2518	57	57	4.915	4.922
10101053_16	3.86	4.04	4.09	4.16	4.11	4.17		2579	2576	84	84	7.935	7.911
10101221_1	3.37	3.63	3.78	3.85	3.80	3.84		10	8	34	34	2.957	2.936
10101221_2	3.56	3.76	3.75	3.81	3.75	3.81		47	44	263	263	22.74	22.7
10101221_3	3.45	3.77	3.90	3.99	3.92	3.99		350	348	35	35	2.71	2.7
10101221_4	3.52	3.76	3.83	4.00	3.84	4.00		409	394	68	80	5.467	5.981
10101221_5	3.33	3.56	3.67	3.79	3.68	3.78		998	996	30	35	2.267	2.452
10101221_6	3.43	3.58	3.73	3.73	3.75	3.74		1102	1099	40	40	3.595	3.53
10101221_7	3.45	3.59	3.84	3.75	3.87	3.75		1222	1219	34	35	3.288	3.313
10101221_8	3.50	3.62	3.79	3.77	3.79	3.77		1385	1382	175	176	15.48	15.48
10101221_9	3.43	3.56	3.77	3.77	3.80	3.78		1873	1870	52	53	4.299	4.3
10110924_1	3.42	3.64	3.50	3.71	3.59	3.70		417	415	34	33	2.884	2.854
10110924_2	4.03	4.29	4.19	4.38	4.19	4.37		454	452	38	37	3.391	3.336
10110924_3	3.26	3.41	3.43	3.56	3.45	3.55		680	707	73	44	5.281	3.275
10110924_4	3.38	3.54	3.71	3.73	3.72	3.74		886	883	36	36	3.245	3.212
10110924_5	3.58	3.81	3.87	4.02	3.87	4.02		926	923	151	152	14.21	14.19
10110924_6	3.66	3.88	3.93	4.07	3.97	4.07		1078	1076	61	61	5.941	5.936
10110924_7	3.76	4.03	4.12	4.28	4.13	4.29		1141	1138	59	75	5.574	6.968
10110924_8	3.33	3.61	3.57	3.73	3.59	3.72		1616	1613	44	45	3.559	3.561
10110924_9	3.65	3.83	3.89	3.96	3.92	3.96		1661	1659	172	519	13.23	43.4
10110924_10	3.69	#N/A	3.89	#N/A	3.90	#N/A		1834	#N/A	326	#N/A	28.55	#N/A
10110924_11	3.86	3.94	4.23	4.22	4.26	4.21		2239	2236	45	45	4.087	4.056
10110924_12	3.54	3.70	3.86	3.87	3.87	3.87		2366	2363	50	136	4.464	11.79
10110924_13	3.75	#N/A	4.00	#N/A	4.01	#N/A		2417	#N/A	85	#N/A	7.311	#N/A
10110924_14	3.79	3.75	3.99	3.86	4.01	3.86		2503	2500	44	45	4.094	4.088
10110924_15	3.73	3.69	3.97	3.79	3.99	3.79		2549	2547	90	89	7.943	7.89
10110924_16	4.02	4.03	4.35	4.22	4.35	4.22		2640	2638	200	199	17.49	17.42
10111027_1	3.58	3.81	3.87	4.07	3.90	4.06		661	658	35	35	2.581	2.535
10111027_2	3.55	3.75	3.83	3.96	3.86	3.96		1029	1026	77	77	6.3	6.237
10111027_3	3.54	3.77	3.79	3.94	3.84	3.96		1122	1119	42	43	3.208	3.214
10111027_4	3.36	3.53	3.55	3.65	3.56	3.65		1560	1557	52	53	4.207	4.208
10111027_5	3.37	3.57	3.61	3.70	3.66	3.71		1617	1614	38	38	2.692	2.675
10111027_6	3.49	3.68	3.74	3.84	3.75	3.84		1656	1654	86	86	7.969	7.924
10111027_7	3.58	3.78	3.91	4.01	3.92	4.02		1789	1787	59	58	5.398	5.346
10111027_8	3.87	4.12	4.05	4.26	4.08	4.27		1849	1846	31	32	2.865	2.882
10111027_9	3.70	3.90	4.19	4.19	4.23	4.19		1889	1887	34	34	2.911	2.88
10111150_1	3.68	3.93	3.97	4.06	3.98	4.06		6	4	36	35	2.91	2.845
10111150_2	3.67	3.98	3.92	4.19	3.94	4.20		125	115	51	59	3.982	4.496
10111150_3	3.27	3.57	3.46	3.62	3.48	3.62		215	212	35	35	2.28	2.259
10111150_4	3.32	3.63	3.69	3.83	3.70	3.83		287	285	30	30	1.999	1.972
10111150_5	3.36	3.55	3.63	3.74	3.64	3.74		340	338	56	55	4.212	4.148
10111150_6	3.40	3.56	3.70	3.77	3.70	3.77		401	399	136	57	10.94	4.02
10111150_7	3.61	3.70	3.94	3.88	3.95	3.88		539	457	90	77	8.582	6.734
10111150_8	3.63	3.83	3.97	4.03	3.98	4.04		630	536	76	167	7.29	15.82
10111150_9	3.49	3.71	3.79	3.88	3.80	3.88		722	720	90	90	8.235	8.186
10111150_10	3.65	3.86	3.99	4.07	4.00	4.06		815	812	190	191	18.24	18.24
10111150_11	3.40	3.52	3.77	3.77	3.78	3.78		1048	1045	37	37	3.172	3.151
10111150_12	4.11	3.98	4.62	4.11	4.64	4.12		1387	1384	44	213	4.157	19.52
10111150_13	3.70	#N/A	3.87	#N/A	3.90	#N/A		1432	#N/A	167	#N/A	15.38	#N/A

10111150_14	3.55	3.83	3.79	3.94	3.81	3.95		1620	1598	39	58	3.546	4.914
10111150_15	4.07	4.31	4.37	4.47	4.38	4.48		1661	1658	62	62	5.515	5.472
10111150_16	3.29	3.41	3.42	3.46	3.43	3.46		2627	2624	37	38	2.716	2.724
10111150_17	3.37	3.46	3.50	3.53	3.51	3.53		2674	2672	67	66	5.006	4.941
10111150_18	3.52	3.79	3.78	3.97	3.79	3.97		2835	2832	71	71	5.344	5.294
10111150_19	3.52	3.72	3.78	3.84	3.85	3.83		2908	2906	35	35	3.169	3.161
10111300_1	3.44	3.71	3.72	3.94	3.73	3.94		42	40	65	65	5.926	5.915
10111300_2	3.83	4.11	4.01	4.23	4.02	4.23		109	106	42	43	4.002	4.001
10111300_3	3.56	3.85	3.89	4.12	3.90	4.12		153	151	78	77	7.475	7.387
10111300_4	3.62	3.87	3.96	4.13	3.96	4.14		233	230	56	56	5.414	5.377
10111300_5	3.54	3.79	3.90	4.06	3.93	4.06		293	291	46	46	4.324	4.338
10111300_6	3.36	3.61	3.55	3.81	3.58	3.82		414	411	112	113	8.16	8.119
10111300_7	3.41	3.67	3.65	3.94	3.66	3.94		570	568	139	138	10.35	10.3
10111300_8	3.47	3.70	3.80	3.98	3.83	3.99		712	710	74	73	6.946	6.877
10111300_9	3.88	4.15	4.10	4.33	4.11	4.33		789	786	195	195	17.45	17.4
10111300_10	3.69	4.09	4.08	4.42	4.13	4.42		986	984	59	41	4.824	3.746
10111300_11	3.24	3.56	3.56	3.84	3.58	3.84		1157	1154	34	35	2.786	2.802
10111300_12	3.70	3.96	3.95	4.18	4.00	4.19		1607	1604	59	59	5.022	5.004
10111300_13	3.77	4.03	4.14	4.33	4.18	4.33		1754	1751	36	36	3.189	3.178
10111300_14	3.65	3.92	3.96	4.18	3.98	4.19		1867	1864	58	58	5.555	5.536
10111300_15	3.37	3.60	3.72	3.91	3.76	3.91		1972	1970	35	34	3.207	3.16
10111300_16	3.37	3.62	3.52	3.80	3.52	3.80		2147	2145	42	40	3.058	2.977
10111300_17	3.71	3.98	3.99	4.23	4.00	4.24		2308	2306	59	59	5.395	5.364
10111300_18	3.61	3.86	3.93	4.15	3.96	4.16		2553	2551	34	33	2.59	2.551
10111401_1	3.82	4.13	4.11	4.37	4.18	4.39		9	7	35	34	3.249	3.202
10111401_2	3.53	3.80	3.76	3.98	3.78	3.99		46	43	34	34	3.093	3.083
10111401_3	3.56	3.94	3.84	4.11	3.87	4.11		294	292	39	39	3.7	3.667
10111401_4	3.61	3.86	3.92	4.11	3.93	4.10		362	359	36	36	3.41	3.392
10111401_5	3.62	3.90	3.84	4.07	3.86	4.08		399	396	42	42	3.882	3.864
10111401_6	3.77	4.06	4.02	4.25	4.06	4.27		1226	1223	82	83	7.422	7.413
10111401_7	3.49	3.76	3.70	3.86	3.75	3.88		1578	1575	33	34	2.916	2.924
10111501_1	4.21	4.52	4.46	4.74	4.50	4.76		68	65	36	37	2.859	2.876
10111501_2	3.17	3.49	3.34	3.56	3.34	3.55		221	218	34	35	2.215	2.227
10111501_3	3.36	3.73	3.52	3.78	3.53	3.79		259	256	40	40	2.345	2.316
10111501_4	3.51	3.85	3.65	3.91	3.69	3.92		305	303	45	49	3.348	3.51
10111501_5	3.44	3.69	3.64	3.77	3.65	3.77		398	396	48	47	4.331	4.255
10111501_6	3.51	3.73	3.65	3.77	3.66	3.76		463	460	53	53	4.419	4.386
10111501_7	3.61	3.92	3.91	4.13	3.93	4.13		1210	1207	136	136	12.63	12.55
10111501_8	3.64	3.93	3.94	4.11	3.98	4.12		1348	1345	34	34	3.186	3.142
10111501_9	3.30	3.59	3.47	3.67	3.49	3.66		1487	1485	44	44	3.122	3.124
10111501_10	3.48	3.84	3.71	3.92	3.73	3.93		1583	1580	40	40	3.494	3.459
10111501_11	3.96	4.17	4.34	4.38	4.37	4.40		1741	1738	44	68	3.877	5.939
10111501_12	3.91	4.19	4.11	4.29	4.14	4.31		1810	1807	86	87	7.904	7.941
10111501_13	3.85	4.15	4.05	4.22	4.07	4.22		1906	1904	187	186	16.84	16.78
10111501_14	3.74	4.04	3.94	4.11	3.95	4.12		2117	2092	105	127	9.507	10.92
10120600_1	3.23	3.47	3.29	3.46	3.31	3.46		10	7	37	37	1.857	1.84
10120600_2	3.13	3.49	3.16	3.43	3.19	3.47		49	46	41	42	2.406	2.41
10120600_3	3.04	3.38	3.12	3.38	3.14	3.38		100	91	60	67	4.016	4.368
10120600_4	3.44	3.70	3.47	3.62	3.49	3.63		175	159	36	49	3.256	4.147
10120600_5	3.24	3.64	3.31	3.66	3.46	3.67		234	232	36	35	2.523	2.456

10120600_6	2.98	3.41	3.04	3.37	3.05	3.37	343	341	58	58	3.304	3.276
10120600_7	3.00	3.41	3.12	3.40	3.13	3.39	403	400	37	37	2.122	2.099
10120600_8	3.23	3.70	3.38	3.72	3.39	3.72	442	440	99	98	6.939	6.859
10120600_9	3.07	3.32	3.24	3.34	3.28	3.36	600	598	31	30	2.25	2.203
10120600_10	3.75	4.18	4.10	4.29	4.12	4.30	644	641	35	36	3.153	3.165
10120600_11	3.51	3.93	3.70	3.90	3.72	3.91	681	678	36	37	2.948	2.969
10120600_12	3.57	3.95	3.76	3.95	3.77	3.95	718	716	392	392	36.31	36.22
10120600_13	3.01	3.29	3.18	3.35	3.20	3.35	2716	2714	31	31	1.712	1.702
10120600_14	3.42	3.61	3.62	3.74	3.67	3.74	2857	2855	34	33	2.099	2.047
10120600_15	2.92	3.19	3.01	3.21	3.02	3.21	2960	2957	35	35	1.713	1.693
10120705_1	3.48	3.66	3.68	3.72	3.70	3.72	256	254	35	35	2.885	2.886
10120705_2	2.75	2.95	2.84	3.00	2.86	2.99	451	449	34	34	1.528	1.512
10120705_3	3.14	3.34	3.19	3.36	3.19	3.36	751	749	69	68	3.31	3.255
10120705_4	2.79		2.83		2.85		908		31		1.248	
10120705_5	3.01	3.27	3.19	3.35	3.23	3.40	949	947	41	40	2.346	2.289
10120705_6	3.37	3.64	3.58	3.73	3.67	3.75	992	990	44	43	2.697	2.63
10120705_7	3.49	3.73	3.74	3.87	3.76	3.87	1057	1055	101	100	7.625	7.565
10120705_8	3.45	#N/A	3.64	#N/A	3.68	#N/A	1478	#N/A	32	#N/A	1.865	#N/A
10120705_9	2.88	2.90	2.96	2.90	2.97	2.90	2116	2114	60	59	3.818	3.763
10120705_10	3.57	3.73	3.73	3.77	3.78	3.79	2520	2518	37	36	3.009	2.94
10120705_11	3.20	3.36	3.43	3.51	3.43	3.51	2585	2582	64	62	4.387	4.277
10120705_12	3.34	3.48	3.54	3.54	3.56	3.54	2877	2875	44	51	3.408	3.795
10120805_1	4.16	4.20	4.66	4.49	4.66	4.51	183	180	41	42	3.686	3.697
10120805_2	3.10	3.17	3.23	3.23	3.24	3.23	321	319	38	37	1.9	1.84
10120805_3	3.20	#N/A	3.38	#N/A	3.40	#N/A	381	#N/A	30	#N/A	1.797	#N/A
10120805_4	3.63	3.68	3.84	3.73	3.85	3.73	528	526	59	58	5.212	5.161
10120805_5	3.32	3.38	3.54	3.46	3.56	3.45	661	658	66	66	4.79	4.756
10120805_6	3.75	3.91	4.10	4.03	4.11	4.03	729	726	53	54	5.126	5.125
10120805_7	3.32	3.43	3.56	3.50	3.56	3.50	823	820	58	58	4.554	4.521
10120805_8	2.97	2.97	3.06	2.95	3.06	2.95	940	938	32	31	2.23	2.181
10120805_9	3.70	3.81	3.97	3.90	4.03	3.90	990	988	40	39	2.871	2.821
10120805_10	3.72	3.73	3.92	3.79	3.96	3.81	1419	1416	43	44	3.656	3.657
10120805_11	3.22	3.24	3.42	3.30	3.51	3.35	1997	1994	37	38	2.406	2.406
10120805_12	3.29	3.27	3.46	3.29	3.49	3.30	2344	2342	36	35	2.278	2.227
10120805_13	3.40	3.47	3.51	3.50	3.51	3.50	2388	2386	59	59	2.926	2.9
10120805_14	3.37	3.39	3.49	3.44	3.49	3.44	2499	2496	73	73	4.345	4.318
10120805_15	3.23	3.29	3.34	3.34	3.34	3.34	2679	2677	31	30	1.412	1.369
10120805_16	3.26	3.24	3.38	3.27	3.38	3.27	2735	2733	42	42	2.511	2.496
10120905_1	3.60	3.75	3.92	3.90	3.93	3.90	19	17	65	65	5.395	5.342
10120905_2	3.69	3.80	4.01	3.97	4.01	3.97	87	85	115	115	10.43	10.4
10120905_3	3.71	3.79	4.06	3.96	4.09	3.97	210	208	67	66	6.373	6.327
10120905_4	#N/A	3.61	#N/A	3.76	#N/A	3.76	#N/A	526	#N/A	34	#N/A	2.277
10120905_5	3.79	3.86	3.75	3.95	4.02	3.96	632	629	34	34	2.76	2.758
10120905_6	3.67	3.81	3.89	3.88	3.91	3.88	668	665	62	63	5.532	5.534
10120905_7	3.76	3.85	4.01	3.94	4.03	3.96	760	758	44	43	3.183	3.144
10120905_8	3.64	3.77	3.80	3.82	3.84	3.82	805	802	53	54	4.455	4.475
10120905_9	3.59	3.74	3.91	3.91	3.95	3.92	860	858	67	66	5.318	5.224
10121047_1	3.81	3.88	3.91	3.95	3.94	3.94	167	150	40	55	3.675	4.879
10121047_2	3.66	3.85	4.04	4.09	4.04	4.09	210	207	43	44	4.119	4.115
10121047_3	3.79	3.92	4.18	4.17	4.20	4.17	255	252	36	37	3.452	3.452

10121047_4	3.82	3.92	4.08	4.06	4.09	4.06		296	293	232	232	21.7	21.66
10121047_5	3.75	3.98	4.13	4.06	4.16	4.12		530	526	36	38	3.334	3.363
10121047_6	3.64	3.76	3.91	3.93	3.93	3.93		1353	1351	43	42	3.611	3.565
10121047_7	3.85	4.06	4.04	4.14	4.10	4.16		2099	2097	36	36	3.343	3.334
10121047_8	3.55	3.71	3.92	3.91	3.97	3.92		2248	2246	36	35	3.083	3.025
10121047_9	3.70	3.93	3.97	4.01	4.00	4.01		2495	2492	38	39	2.771	2.789
10121047_10	3.47	3.68	3.71	3.89	3.76	3.92		2702	2700	31	31	2.301	2.303
10121047_11	3.70	3.87	3.98	4.01	4.10	4.03		2761	2758	42	43	3.301	3.309
10121047_12	3.76	3.91	3.99	3.99	4.02	4.01		2913	2910	36	36	3.25	3.241
10121047_13	3.60	#N/A	3.98	#N/A	4.00	#N/A		2951	#N/A	48	#N/A	4.068	#N/A
10121148_1	3.50	3.84	3.95	4.08	3.96	4.09		14	11	40	53	3.35	4.221
10121148_2	3.29		3.52		3.51			1814		47		3.918	